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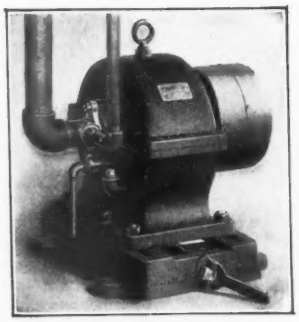

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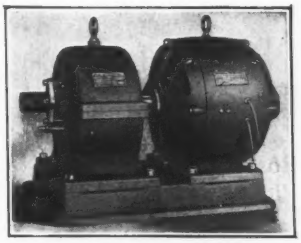

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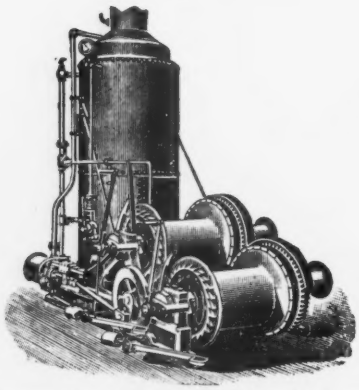

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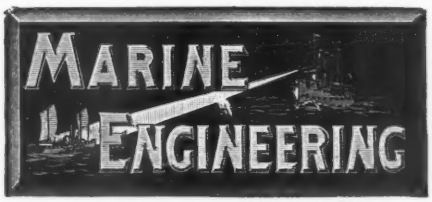

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THE GUNNISON TUNNEL OF THE UNCOMPAHGRE IRRIGATION PROJECT

By M. G. DOLL.*

It is only by close acquaintance with some specific undertaking, such as the one described in this article, that it is possible to realize the extent of the work being done by the U. S. Reclamation Service. The Uncompahgre project is but one of dozens of irrigation systems which are being developed throughout the West. Some of these are larger in extent and more important in their results than this, but from an engineering standpoint, none is of greater interest. The driving of a tunnel nearly six miles in length through materials ranging from soft mud to hard rock is a large enterprise, particularly when it is remembered that owing to the height of the hill penetrated, nearly five miles of the tunnel are being driven from two headings, one at each end, without intermediate shafts for ventilation and removal of excavated materials. This tunnel is the longest, although not the largest in point of diameter, in the United States, and as far as the writer's information goes, it is the longest in the world, driven as above described from only two openings and without intermediate shafts. The methods and the progress made, as described below, reflect great credit upon the skill and executive ability of the government engineering force in charge of the construction.

VIEW FROM TOP OF SHAFT FOR HEADINGS 2 AND 3.

THE IRRIGATION PROJECT.

The Gunnison Tunnel is part of the Uncompahge Valley Irrigation Project, undertaken by the United States Reclamation Service. This project when completed will reclaim about 150,000 acres of land, in the Valley of the Uncompahgre river, in a portion of Montrose and Delta counties, in the west central part of Colorado. (See general map.) Small portions of the Uncompahgre Valley have been under irrigation for some time, by water drawn from the Uncompahgre river, but owing to the limited supply of this water, the irrigation necessarily had to be restricted to a small area. However, these preliminary experiments served to show the possibilities of this land, if it could be supplied with a sufficient amount of water.

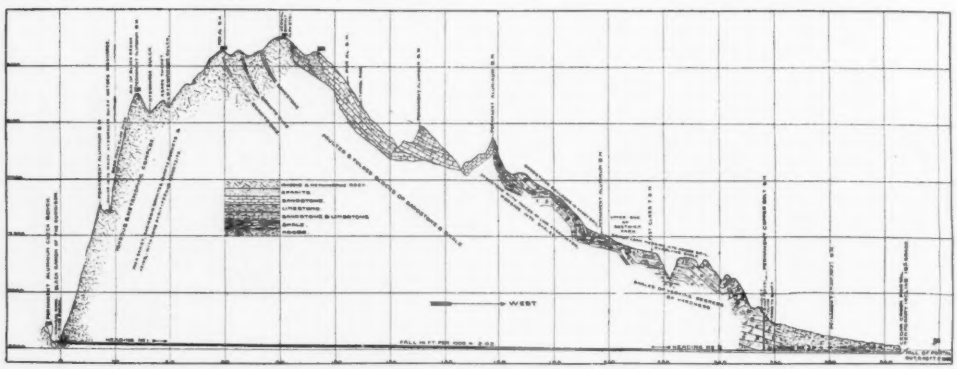
The soil in the Uncompahgre Valley is practically of two kinds, an adobe on one side

*1748 Broadway, Denver, Colo.

and a sandy soil on the other. The adobe has proven to be adapted especially to wheat and other small grains, in general, while the sandy soil is more strictly adapted to fruits, potatoes and sugar beets. The productive season of this section has been in the past rather long, spring opening early and the autumn frosts coming late. These facts, coupled with the large choice of crops, should not only make the project a thorough success, but they should also make this one of the ideal sections of the State for homesteads.

To accomplish this condiiton of affairs it was calculated that an additional water supply of 1,300 cubic feet per second, during the productive season, would be necessary. Records of the Gunnison river showed that an average maximum flow of 14,200 cubic feet per second occurred in June and a minimum of 750 cubic feet per second in September; during April of this year there was an average flow of 1,481 cubic feet per second. The Gunnison river, therefore, carried sufficient water to furnish the necessary supply for the Uncompahgre Valley project, but it was locked in one of the characteristic cañons of Colorado, with nearly perpendicular walls of solid rock about 1,500 feet in height. After a thorough investigation on the part of the Reclamation Service, it was finally considered feasible to divert the water from the Gunnison cañon by running a tunnel nearly six miles in length under Vernal Mesa.

Work was begun on this tunnel in February of 1905. On July 1st, 1906, the total distance driven was 13,767 feet, of which 1,321 feet were completed during the month of June. At the present time it is expected that the work will be completed, with the exception of a part of the concreting in the solid rock portion, so that the flow of water through the tunnel may begin in the spring of 1908. The remainder of the concrete construction will be completed during the winter of the same year. During subsequent years it is intended to maintain a full water supply from April 1st to October 1st. A diminished flow will be maintained for cattle water for some time previous to April 1st and continued for some time after October 1st. The cost of the entire project, complete, is estimated at $2,500,000.



PROFILE OF THE GUNNISON TUNNEL.

(Redrawn from the Government Map) Horizontal scale 1 inch = 4125 feet; Vertical scale, 1 inch = 735 feet.

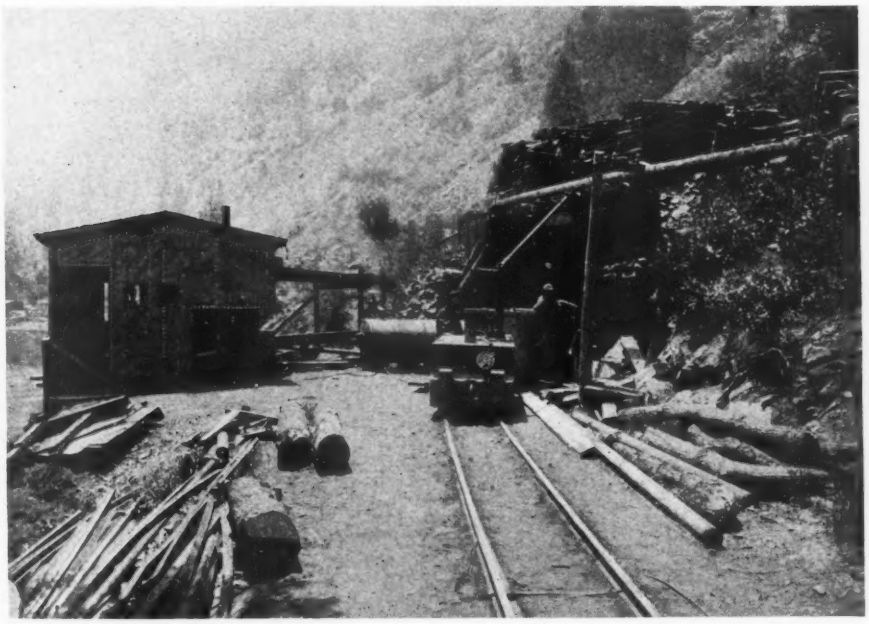
THE TUNNEL—GENERAL FEATURES.

The east or river portal of the Gunnison tunnel is situated in the cañon of the Gunnison river, in Montrose county, altitude (grade line of the tunnel at Section No. 1) 6,533 feet. (See general and profile maps.) The grade line of the tunnel is about 6 feet below the lowest point of the bed of the river. At the present writing, the plans and specifications for the controlling gates have not been passed upon. The total length of the tunnel from the east to the west portal will be 30,582 feet, with a fall of 2.02 feet per 1,000 from the east to the west portal. It is designed to have a capacity of 1,300 cubic feet of water per second with a velocity of 12.6 feet per second.

The tunnel is ten feet in width at grade, with walls slightly sloping to the base of the arched roof or invert, where it is 11 feet wide. The height from the floor to the highest point varies from 11 feet 5 inches to 12 feet. The greatest depth from the surface of Vernal Mesa to the tunnel is 2,200 feet. The accompanying profile map and cross section of the tunnel at different points indicate the extent

and character of the undertaking.

The postoffice name of the camp at the east portal is River Portal; that at the west end of the tunnel is Lujane. They are connected by a government road about 12 miles long, passing over Vernal Mesa. This road and a general view of the Mesa are shown in the accompanying illustrations. The building of this road was an engineering feat in itself, especially on the River Portal side, where the walls of the cañon are extremely steep and rugged, the summit being nearly 2,000 feet above the river.



THE EAST, OR RIVER PORTAL; TO THE LEFT IS THE HOIST HOUSE.

THE DISTRIBUTING CANALS.

From the West Portal, 1,250 second-feet of the water will be carried through a cement-lined canal (50 second-feet having been diverted to Cedar creek near the portal) to the Uncompahgre river, where a number of branches are made, the bed of the Uncompahgre river also being utilized to convey a portion of the water. As the grade from the West Portal to the Valley is quite steep, it will be necessary to lower the water by gradual stages, so that the walls and bed of the canal may not be destroyed by the velocity of the flow. This fall is accomplished by a series of 14 steps, which are so placed as to cause the water to fall on a grating of 80 pound steel rails, spaced 8 inches apart, the rails being held in place by a double concrete arch. This grating serves to break the force of the fall and also to catch any debris which may be carried down the canal. From this grating the water falls into a basin of sufficient depth to form a water cushion, thus preventing any damage to the concrete lining.

TUNNEL CONSTRUCTION—MATERIALS ENCOUNTERED.

The main tunnel was driven from four separate headings (see profile map), No. 1 at the east portal, Nos. 2 and 3 from a 200-foot shaft which was sunk about a mile from the west portal, and No. 4 from the west portal of the tunnel. Nos. 3 and 4 have since met, thus leaving work at Nos. 1 and 2 in active operation at the present time. Heading No. 1 was driven in a hard rock formation from the beginning, while the materials in Nos. 2, 3 and 4 vary from a soft adobe mud in No. 4 to a very soft, extremely brittle shale in No. 2. The ground in No. 4 and the latter part of No. 3 just previous to the junction of Nos. 4 and 3 consisted of a soft swelling adobe mud.

The sections of the tunnel running through the mud and soft shale were timbered with

eight and twelve inch pine timbers, and the whole tunnel section is lined with concrete.

METHOD IN EARTH AND SOFT ROCK SECTIONS.

Heading No. 2 and the first part of No. 3, in soft shale, were advanced by a bench and overcut heading system, employing air-driven rotary drills or coal augers. With a few exceptions, where the ground was firmer than ordinary, the timbers were advanced by the crown bar system, which consisted in carrying the roof on temporary stringers held in place by jack-bars, until the permanent timbering could be finished. Very rapid work was accomplished in this ground, in a few cases over 600 lineal feet being driven during one month.

The muck from headings Nos. 2 and 3 was hoisted through the shaft, located at their starting point, while that from No. 4 was hauled in side dump tunnel cars, holding 1¼ cu. yds. each, through the west portal and run out on a dump at the side of the main canal. In heading No. 2 the tunnel has recently passed through a deposit of sea shells, some of which were three and four feet in diameter. These shells sometimes fell without warning, bringing down masses of shale from the roof of the tunnel.

During the latter part of July of this year, the hoist originally used for headings Nos. 2 and 3 was put out of commission, and the muck from No. 2 heading is now being carried through the west portal of the tunnel. This is a very economical operation, as the loaded cars are carried on the down grade, therefore the amount of muck moved by the mine locomotives depends largely on the number of empty cars the locomotive is able to haul up the grade. At the foot of the shaft a large room has been constructed. It is intended to install one of the concrete plants in this room, and divide the shaft into two compartments, to be utilized for supplying by gravity feed the gravel and sand used in the concrete. A very good grade of these materials is obtained from the Mesa in the near vicinity. The concreting will be simultaneously begun in a number of places in the west portion of the tunnel, as soon as the mixing machinery can be installed.

TOWN OF RIVER PORTAL AND THE GUNNISON RIVER; THE SMALL CROSS ON THE LEFT BANK INDICATES THE EAST PORTAL OF THE TUNNEL.

EAST PORTAL—ROCK CONSTRUCTION.

In heading No. 1 (driven from the east portal) a different condition of affairs exists. This heading has been in very hard rock ever since the beginning of operations, and from all indications it will probably continue so until headings Nos. 1 and 2 meet.

Owing to the fact that the grade line of the east portal is six feet below the bed of the river, it was necessary to make an opening above the high-water mark of the river, and then drop sharply to the grade line. This causes a short, steep incline, at the mouth of the tunnel, which necessitates the use of a small hoist, for hoisting and lowering the electric locomotive and the two-yard loaded muck cars. These cars are handled on the dump by a stiff leg derrick designed and built on the ground by the government engineers. (See cut, page 4288).

THE WEST PORTAL AND TOWN OF LUJANE.

The rock work at the east portal was begun by contract. Under the supervision of the contractors the work was advanced by an undercutting drift, the roof being subsequently shot down. Owing to this method, and to deficiencies in equipment, as will be shown below, progress was unsatisfactory and the contractors abandoned their task. The work was then taken up by the United States Reclamation Service, and overcut heading and bench work was installed. Since this time the work has been making very satisfactory progress.

As mentioned above, the height of the hill over the tunnel prevents the sinking of a shaft for ventilation and removal of materials. Ventilation is provided by means of powerful blowers at either end of the tunnel, and no trouble has been experienced on this score. All materials excavated are removed through the tunnel itself. The method employed in the west heading has already been described. From the river heading the muck cars are run to the bench on a double track, the forward cars being filled by the bench muckers and the after cars by the heading muckers. The muck from the heading is carried to the rear cars on wheelbarrows, over the bench and onto a gang plank, supported above the cars on long mining bars. This method of driving a tunnel has shown its merits and proven its practicability in its more rapid advance and in lower cost of operation, as demonstrated by complete records of these details for both systems, kept by the engineering force.

ROCK DRILLING.

The original contractors had installed a Leyner air plant with Water Leyner drills, and the use of this plant was continued under the new system. Four Leyner drills were used in the heading and two on the bench. In February of this year, Mr. W. H. Davis, a tunnel man of experience, was appointed superintendent of heading No. 1. Shortly be-

fore April 1st Sullivan standard three-inch drills were substituted for the Leyner machines. This change produced a marked increase in the progress of the tunnel, as well as a considerable saving in the cost of drill repairs, even though the rock became continually harder as the tunnel advanced. It was also found that four Sullivan drills in the heading with one on the bench, were sufficient to successfully carry on the work. The following tables, compiled from the records kept by the government engineers, will give an idea of the progress made up to date.

The following results were tabulated from a special report in the engineer's office, comparing the relative cost of the rock drill repairs on the Leyner drills, for a period of six months, from September 1st, 1905, to March 1st, 1906, with those on the Sullivan drills for a period of three months, from April 1st, 1906, to July 1st, 1906. These costs are simply for the repair parts required for the drills, the cost of the steel used, and of the time required by the mechanic in making the repairs:

Cost per lineal foot of completed tunnel section, for Leyner drills.....	$4.65
Cost per lineal foot of completed tunnel section, for Sullivan drills.....	.86
Cost per lineal foot of holes drilled, for the Leyner drills	.31
Cost per lineal foot of holes drilled, for the Sullivan drills	.03

The engineer's records also show the average cost of repairs, steel and labor for one Sullivan drill per month to be approximately 29 per cent. of the cost of repairs for one Leyner drill per month.

POWER PLANTS AND EQUIPMENT.

The power plants at Lujane and River Portal are constantly changing as the work advances. The former has a tendency to decrease in extent, owing to the smaller number of headings being supplied with power, and to the fact that the grade of the tunnel is toward the west portal. The plant at River Portal, conversely, has a tendency to increase. At the present writing the Lujane plant proper comprises three electric generators rated at 275 kw., which operate three high speed engines; two straight line and one cross compound steam driven compressors with a total capacity of 1,600 cubic feet of free air per minute, and boilers of 500 H. P. capacity. In this end of the tunnel are installed suitable pumps, a 75 H. P. air hoist, two 25 H. P. blowers, and three electric mine locomotives, with a large number of 1¼ yard dump cars. A

THE BLACK CANON OF THE GUNNISON.

number of air-driven coal augers are also in use.

At River Portal the plant comprises the following machinery: One 1,000-foot straight line compressor, and one cross compound, two-stage compressor with a capacity of 600 cubic feet of free air per minute. The air pressure used throughout the tunnel is 100 pounds. Two 100 H. P. engines are driven each by a 75 k. w. 250 volt D. C. generator, and one 55 H. P. engine is driven by a 45 kw. D. C. generator. Steam power is supplied by three 80 H. P. horizontal tubular high pressure boilers, and one 100 H. P. boiler. A suitable equipment of pumps and condensers is installed. In the east tunnel there are in use, two electric mine locomotives, an adequate number of dump cars, one 50 H. P. hoist with a 3 ft. 6 in. clutch-driven drum, and a blower with a capacity of 5,000 cubic feet of air per minute, which is used for ventilating purposes, the air passing through an 18-inch sheet iron ventilator pipe. Eight Sullivan class UD drills are also in use in this heading, five of which are used in driving the tunnel and three kept in reserve. Thirty-pound rails are used for the tunnel track, and the entire length of the tunnel is lighted with 16-candle-power electric lamps, with arc lights in the headings.

TABLE No. 1

Month, 1905	Mar.	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
*Number of lineal feet of full tunnel section completed	53	.....	.....	.....	.....	.....	.....	.....	.....	.....
Number of lineal feet of heading completed.	.....	153	312	165	252	384	355	228	225	181
Geological Formation.	Surface Ground	Hard Schist with Rotten Mica	Hard Schist with Rotten Mica	Gneissoid, hard and dry	Geneissoid Granite	Geneissoid Granite	Gray Granite and Pyritic Quartzite.	Gneissoid Granite	Geneissoid Granite	Rock very brittle with Blue Quartz

*No separate record was kept of the full section of tunnel finished during 1905; full credit was given during each month for the amount of under-cut drift made, but during some of this time the back roof was as much as 1,000 feet behind the face of the drift.

TABLE No. 2

Month, 1906	Jan.	Feb.	March	April	May	June
Number of lineal feet of full section completed.	118	184	234	300	383	373
Number of lineal feet of heading made.	126	204	236	300	377	381
Geological Formation.	Pink to a rotten Granite with schist bordering on soft mud	Hard Mica Schist	Varied to a very hard Granitic Gneiss	Varied from hard Granitic Gneiss to Pink Granite	Short grain and tough very hard to drill	Pink Granite

LABOR AND LABOR CONDITIONS.

The camps at River Portal and Lujane are notably well equipped and well built, both from a sanitary point of view and for the comfort and entertainment of the employes. There are a few tent houses, but most houses are boarded, and both the sides and roofs are covered with roofing paper, which makes a house warm in winter and comparatively cool in summer.

Each camp is equipped with a small but complete hospital in charge of a competent force of trained nurses. All houses are lighted with electricity and connected with a town water supply. A well-organized commissary is operated by the government, also a large boarding house, provided with a large, roomy, well-ventilated sanitary kitchen, where the unmarried men are given board. Besides all these necessaries of life, the government also provides a large, well-lighted and ventilated reading room, a town hall where entertainments, dances and concerts may be held, and

also a billiard room. The streets are kept thoroughly clean, and quite a number of the family houses have small grass plots and flower gardens in their door yards.

The writer wishes to express his obligations to Mr. I. W. McConnell, the constructing engineer in charge, for the courtesy and assistance rendered in obtaining the necessary data for this article, also for the favors extended by members of his engineering staff.

DERRICK FOR DUMPING CARS, RIVER PORTAL.

TURBO-BLOWERS

In a paper recently presented at a meeting of the British Association for the Advancement of Science by Gerald Stoney, on the subject of "Recent Advances in Steam Turbines —Land and Marine," the author described the development of the steam turbine for driving rotary air compressors of the turbine type, which are now being used largely for blowing blast furnaces. The advantages gained are light weight, small foundation, small consumption of oil and above all, high economy of steam over the reciprocating types of blowing engines. The outfits described are generally for about 20,000 cubic feet of free air per minute, and a pressure of ten to fifteen pounds per square inch. A slightly different type is made for about 30,000 cubic feet per minute, at about one pound per square inch pressure. These blowing equipments are being used in several large iron works for dealing with the waste gases from furnaces and for driving these gases through the recovering plant, etc., an important feature being that they do not clog with tar and other matters. Since it is nearly impossible to use economically low-pressure steam at about atmospheric pressure in a reciprocating engine, the exhaust steam turbine becomes an important factor in those cases where there are non-condensing engines and other sources of exhaust steam.

A NEW ROTARY AIR COMPRESSOR

It will probably be of great interest to users of compressed air to know of a new air compressor which, although the pistons reciprocate in the cylinders, might be termed a rotary compressor. The rapidly increasing use of compressed air, due to the development of new applications and to the improvements in air motors and air tools, has brought out a large number of compressors, nearly all of which, however, are of the same general design and construction. Anything new, therefore, in air compressor design, is of more than

VALVE REMOVED FROM THE SHAFT.

ordinary interest, and we believe our readers will be particularly interested in a new type of machine which is illustrated by the accompanying cuts. This machine has many advantages over the prevailing reciprocating type as will be seen from the general construction as described below.

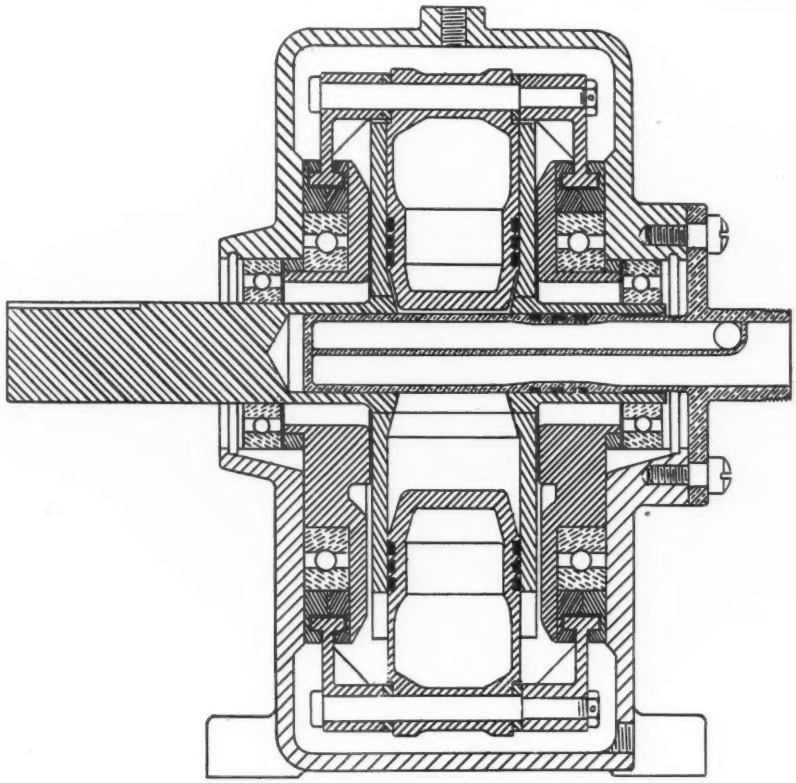
In general outline the machine resembles an electric generator. By removing the upper portion, the entire mechanism is exposed for examination and repair. Where belt power is used for driving a compressor, a belt tightening sub-base is furnished. This in itself is an advantage never before attained in compressor work.

The cylinders are of cast iron completely water-jacketed, and are single acting, radiating from a hollow steel shaft on which the cylinder casting is secured. Each cylinder has a single port at its inner end communicating with the interior of the shaft. These ports are

very large in proportion to the cylinder capacity, allowing for a large intake volume without wire drawing, the shaft being hollow, the intake and exhaust air passing through the valve therein contained as below described.

The cylinders are cast hollow to reduce their weight to a minimum and they are packed with the ordinary type of snap rings; furthermore, they are furnished with projections on their inner ends which fill the ports completely, thus

The inside of the hollow shaft forms the valve seat. The valve is of bronze and is divided into intake and exhaust chambers by a partition. Each chamber has a port at its inner end and a pipe connection at its outer. The valve is anchored to the case, so that as the shaft revolves around it, the cylinder ports pass over the intake port during the outward motion of the piston in the cylinder. At the extreme end of the outward stroke intake is



LONGITUDINAL SECTION OF COMPRESSOR.

making the clearance space only 2 per cent. in the smallest sizes of compressors. They are suspended at their outer end by wrist pins in independent yokes which revolve around a bearing eccentric to the shaft bearing on which the cylinders turn.

Ball bearings are used for the main shaft and the eccentric bearing, this construction being made possible by the fact that they are not subjected to sudden strains or shocks, all motions and stresses being straight, steady and uniform.

cut off and, as the piston is forced back into the cylinder, the air is compressed to approximately the receiver pressure, at which time the cylinder port passes over the discharge port and the air in the cylinder is expelled. The different periods of admission, compression and discharge are automatically accomplished by the revolution of the shaft around the valve. The valve automatically seats itself because of the pressure on the discharge side forcing it against the intake port. Longitudinal leakage is prevented by snap rings running in

grooves in the valve.

The cylinders are thoroughly water-jacketed and, on account of the multiplicity of single acting cylinders, a much greater cooling surface per cubic foot capacity is obtainable than in the ordinary double-acting type of compressor. This, of course, greatly increases the efficiency.

An idea of the simplicity of this machine may be acquired by glancing at the following complete list of parts which go to make up any size of this compressor:

Case, bottom; case, top; 8 cap screws; 1 shaft with cylinders; 4 pistons; 8 yokes; 4 wrist pins; 2 bearings, shaft; 2 bearings, eccentric; 1 drain cock for oil; 2 water connection bolts (hollow); 1 valve; 2 anchor screws for valve; 2 water rings; 1 sub-base complete.

Other important advantages possessed by this compressor are its light weight and perfect balance, enabling it to be operated without being mounted on special foundation. The large intake and port areas in proportion to the piston speed and capacity, the mechanically operated valve and perfect balance make high speed possible without loss in efficiency and economy. This permits of direct connection to electric motors, high speed gas engines or the rotary steam motors manufactured by the same company who make the compressors.

It will be readily appreciated that this design is equally applicable to pneumatic motors and vacuum pumps, both of which are included in this line of apparatus.

At the present time these machines are manufactured in capacities of from 1 cubic foot of free air per minute to 150 cubic feet. Further information may be obtained regarding their design and construction from the manufacturers, The Roteng Engineering Company, 299 Broadway, New York.

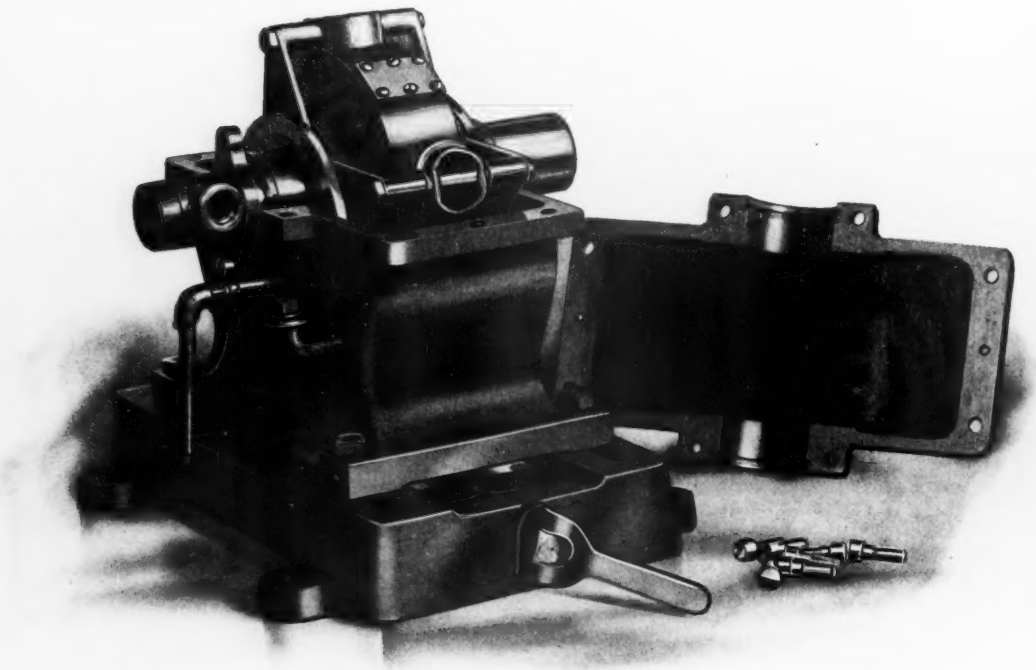


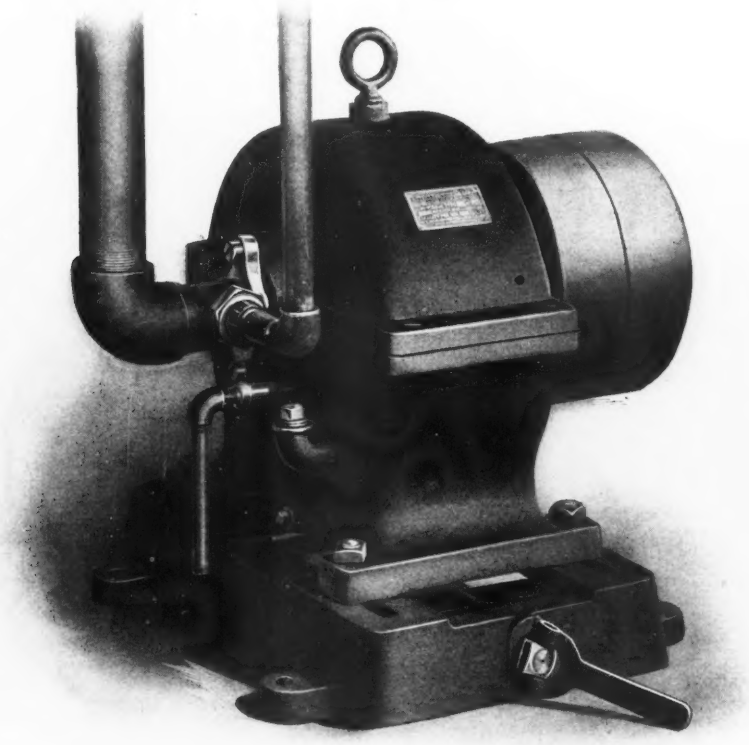
FIG. 2. COMPRESSOR WITH TOP OF CASE REMOVED.

LIQUEFACTION of air is advantageously effected when the air is initially at its critical pressure of about 40 atmospheres, and is cooled by the circulation around it of air which has been cooled by expansion, but to no great extent. An arrangement described by M. G. Claude in *Comptes Rendus* is this: A tube is connected with two liquefiers and an expanding chamber; compressed air is led into this, some going to fill the liquefiers and the remainder passing into the chamber, where it is expanded to fall only to about 160 deg. Cent., passing then round the first liquefier wherein it produces liquefaction at 140 deg., to which temperature it rises itself, then passing on through a second similar expanding chamber, whereby it again falls to 160 deg., afterwards circulating round the second liquefier and acting on it as before, and finally passing away round the inlet tube and so cooling the entering compressed air. By this method 850 c.cm. of liquid air have been obtained per h.p. hour.

COMPRESSED AIR*
Its Production, Transmission and Application

By Lucius I. Wightman.

If there is truth in the saying that old age commands respect, compressed air certainly has strong claims for respectful consideration, for its past reaches far beyond the beginnings of recorded history. It is not a great stretch of the imagination to picture the primeval savage, in a canoe hewn from a log with a stone axe and shaped with the aid of fire, sailing over the streams and inlets of prehistoric lands under the impulse of the wind caught in a rude sail of skins stretched on a crude wooden framework. But this is a practical age and this is a company of very practical men; and in such a place these imaginary pictures have no place.



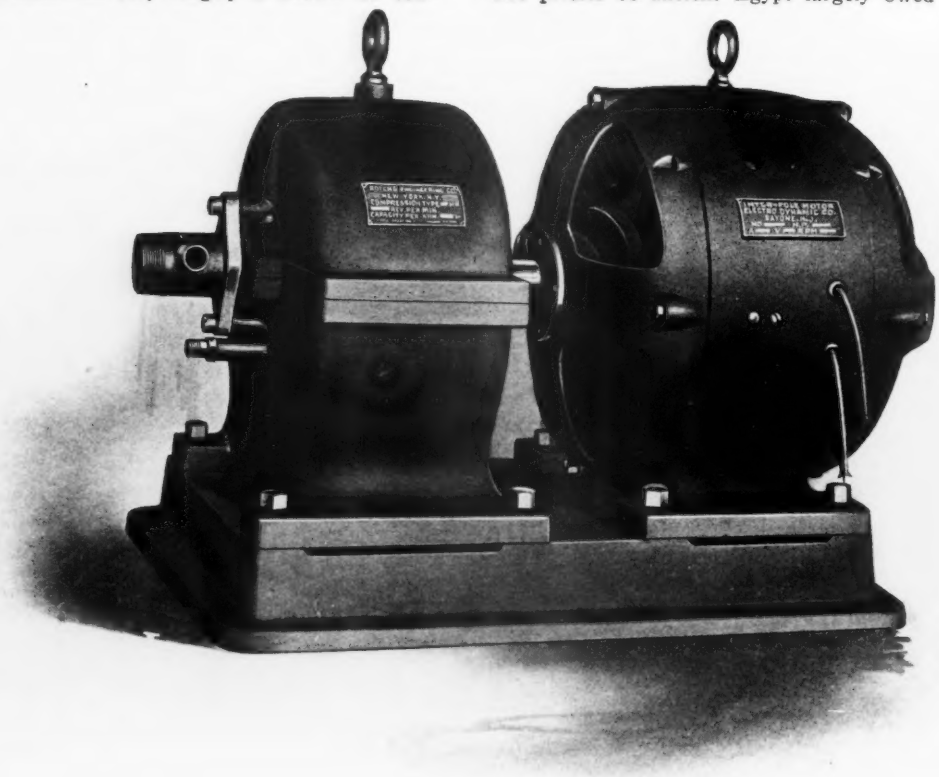
BELT DRIVEN COMPRESSOR MOUNTED ON BELT TIGHTENING SUB-BASE.
As a guide to the weights and sizes, the 12 cu. ft. machine weighs 225 lbs. complete with sub-base and runs at 650 r. p. m. The floor space is 17″ x 21″ and total height to top of eye bolt 22″.

*Abstract of paper read before Engineers Society of Western Pennsylvania.

Coming now to facts, there can be no doubt that air compressed in some degree found practical application in the very earliest ages of man's history. The reduction of metals from their ores was one of the earliest arts acquired by mankind; and the blast furnace must have been the basis of these processes. Just what form these primitive compressors had must be very largely a matter of conjecture. But no doubt their prototypes are found in the appliances still used by savage tribes. Among these may be mentioned the "wind bag" of skin, trodden by the feet, and the wooden box and movable piston, the original of the modern air compressor; and the simple, modest little bellows of the fashionable fireside of to-day is doubtless but little different from those used on the hearths of the most ancient homes.

Heron—or Hero—of Alexandria may perhaps be considered the individual pioneer in air power development. The earliest authentic records of compressed air are found in the "Spiritalia" of this old philosopher. He himself must have had some means, other than the common bellows, for producing the pressures required in operating "Hero's Fountain," which is a feature of all the text books on physics.

The priests of ancient Egypt largely owed their sway over the credulous people to their understanding of the more elementary properties of air. Their supernatural phenomena—so-called—are easily explained to-day by the most simple laws. The miraculous opening of the temple doors when a fire was lighted on the altar was caused simply by the expansion of a volume of air under the heat of the altar fire, this expanded air displacing water from a tank into a suspended bucket, so connected by rollers and cords as to open the doors by its weight. When the fire went out, the doors

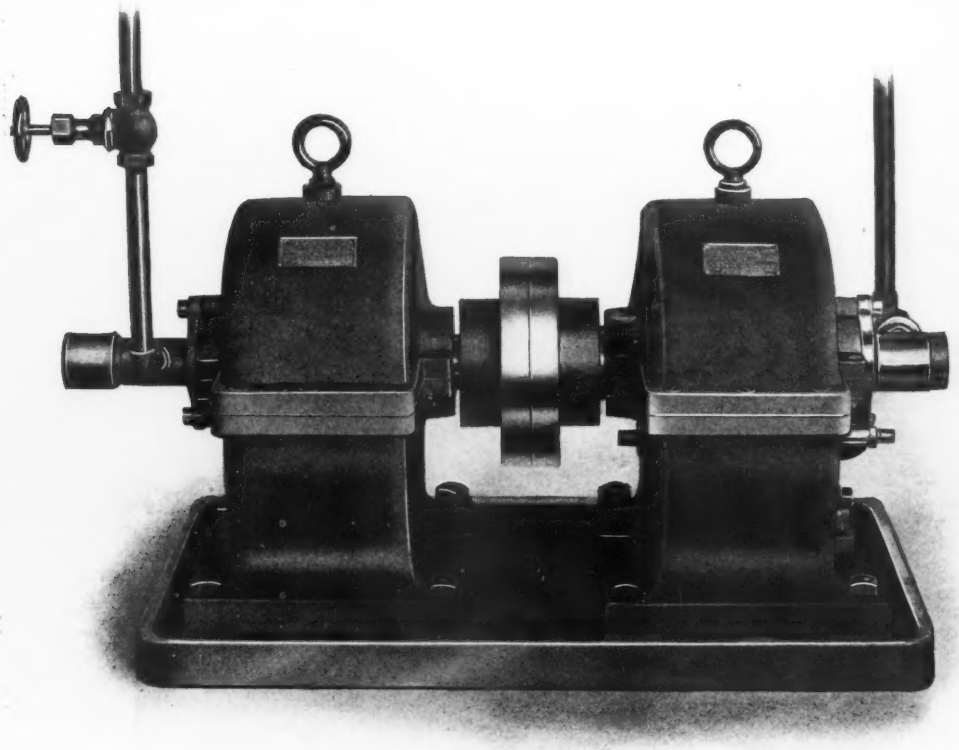


MOTOR DRIVEN ROTENG COMPRESSOR; WATER COOLED; 650 R.P.M.

closed—most supernaturally, to be sure—by a reversal of this process. By the same means did the famous statue of the god Serapis move, on proper occasions. And the awe-inspiring vocal statue of Memnon at Thebes owed its divine voice to the expansion and contraction of an air volume under the heat of morning and the cool of evening.

Hero himself—probably the first "hot air" artist—knew of a means of compressing air by the fall of water in a tube—a precursor of the modern hydraulic compressor. Pliny later mentions a similar device. Ctesibius, a famous Alexandrian engineer of about 120 B. C., invented "wind guns" capable of discharging projectiles. To him must be awarded the palm as the first to produce and apply high pressures.

But these are historic curiosities. Passing on rapidly, in the darkness of the early Christian era and of the Middle Ages, compressed air seems to be lost. It reappears again in the writings of Lord Bacon, who describes a diving bell. Then come the records of achievement of Halley, Smeaton and Brunel, in England, and Von Guericke in Germany. Papin, about 1653, devised a compressed air system involving compression in a water-wheel-driven pump and transmission through a tube to a distance. He also experimented with a pneumatic parcel dispatch. His attempts failed through ignorance of the fundamental physical properties of air.

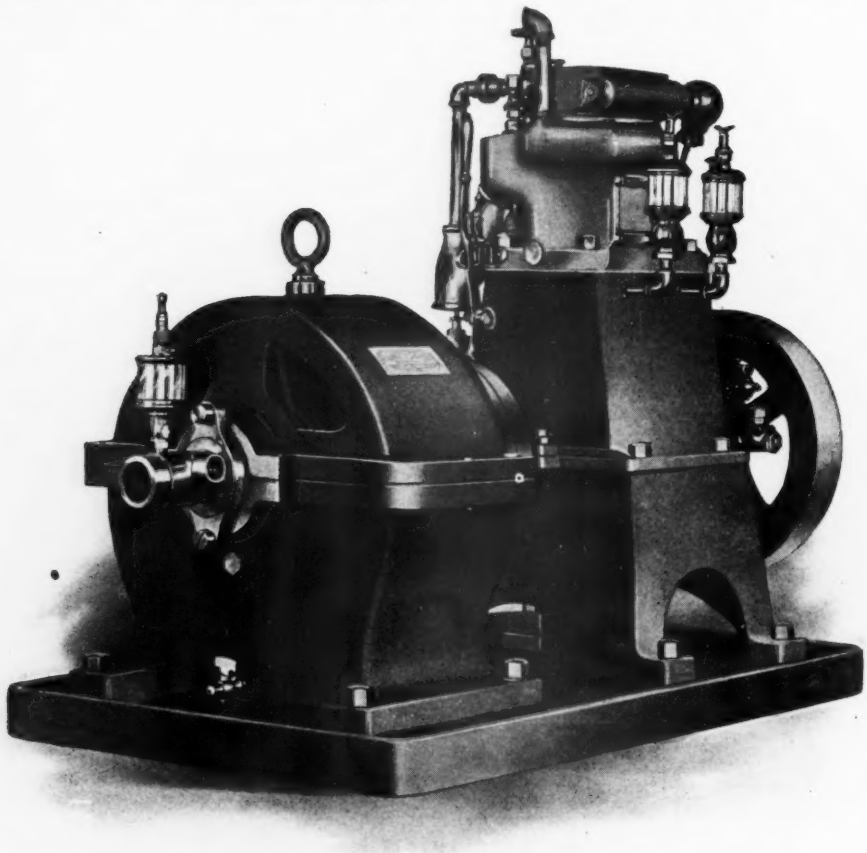


50 CU. FT. PORTABLE STEAM DRIVEN ROTENG COMPRESSOR DIRECT CONNECTED TO ROTENG ENGINE; 550 R.P.M.

The latter part of the eighteenth century and the early part of the nineteenth mark the real birth of air power. During this period Medhurst, the great Danish engineer working in England, laid the foundations of present pneumatic practice. He produced and transmitted pressures of more than 200 lbs., and applied them in motors; he developed a practical, though not economical, system of pneu-

matic dispatch for parcels and persons; he built the first pneumatic automobile in 1800; and he otherwise contributed richly to pneumatic science. Compressed air as a distinct and recognized branch of engineering may be said to date from this period; and under the mechanical renaissance of this time, developments were rapid. The experiments of this time foreshadow, in diversity and daring, the great achievements of to-day. Pneumatic locomotives and motor cars were built and operated. Pneumatic dispatch systems achieved a practical success in London in 1845. America was not behind the old world; and Dr. Gorrie, of New Orleans, built the first refrigerating plant in 1850 and laid the principles upon which rest the tremendous refrigerating systems of to-day.

Mann, in 1829, suggested and patented a system of stage compression with intercooling. But he lost a splendid opportunity to win an immortal name in science by his failure to develop his ideas; they lay dormant for almost half a century. The great Alpine tunnels of the early 70's gave a tremendous impulse to pneumatic development. Sommeiler, on the Mont Cenis bore, used hydraulic compressors. Later developments in this tunnel work brought water piston compressors, with injected jets or sprays for cooling; and pneumatic locomotives were used for haulage in these great bores. The Hoosac tunnel in America first brought the pneumatic rock drill into prominence; and since that time the genius of Burleigh, Ingersoll, Rand, and Sergeant has produced the modern rock drill—probably the greatest single epoch-making device, after the steam engine, in history.



GASOLENE ENGINE DRIVEN ROTENG COMPRESSOR; 650 R. P. M.

This historical sketch, brief as it is, is convincing proof that compressed air has a legitimate claim to dignity and consideration. It has ceased to be a novelty; it has passed the experimental stage. It is to-day a recognized industrial necessity, firmly established as one of the accepted indispensable factors in modern progress.

Compression, or an increase in the density of a body of air, is invariably accompanied by an increase in temperature. This increase in temperature is wholly independent of the rate or means of compression. It is a phenomenon inherently characteristic of the compression process ,and is the direct result of an increased molecular activity in the air. The temperature attained is a function of the degree of compression; but the factor is not a constant, being largest in the early stages of compression and decreasing as the higher pressures are approached. It is a fundamental law of physics that the production of heat demands an expenditure of power; and the power consumed in producing heat in air compression is lost, so far as the inherent economy of compression is concerned. But in actual practice, this heat might be made use of. In one notable air power plant, the heated water from jackets and intercooler was led to the feed-water heater and in this way there was at least a partial recovery of the lost energy. The degree of heating of jacket water depends largely upon its rate of flow over the heated surfaces; and if any attempt is made to use this heated water for boiler feed, there is a fine problem in determining the exact point beyond which the economy ceases to be a virtue. For in a desire to secure hot jacket water, the efficiency of compression may be sacrificed.

This heat of compression is productive of other evils which can—in degree at least—be obviated; and the efforts of compressor designers have from the very first been directed toward this end. In the path of every pneumatic engineer loom two guide posts; the one points the way to economy, and success—the other marks the path to disappointment and failure. The first is isothermal compression—the second is adiabatic compression.

Isothermal compression is a visionary process in which the heat developed in compression is removed as fast as produced and is, therefore, harmless. It would be a realization of Boyles' law, in the expression of which—$P_1 V_1 = P_2 V_2 = K$ the factor T does not appear. Though the best air compressors of to-day closely approximate its values, isothermal compression cannot be fully realized, for a perfect cooling system is not known and, so far as can be seen at present, never will be.

Adiabatic compression, on the other hand, is a grim and forbidding reality—a compression process in which all of the heat developed is retained. It represents the two Primary Laws of Gases in combination; and its expression, involving the three variables of pressure, temperature, and volume, is as follows:

$$P_1 V_1 (T_2+459.2)=P_2 V_2 (T_1+459.2).$$

There is a slim consolation to be derived from the fact that adiabatic compression, too, cannot be wholly realized; for no perfect heat insulator is known. But this fact brings more sorrow to the heart of the scientific investigator than to the practical engineer.

Assuming for a moment that it were possible to compress a volume of air isothermally, and remembering that the product of pressure and volume under this condition will remain constant, it is seen that when the original volume has been reduced one half, the pressure attained must, therefore, be twice the original. But practice rudely shatters these theoretical assumptions. For, as a matter of fact, it is found that the pressure is doubled before the volume is reduced one half; and a very decided rise in temperature is noted. Consideration of these facts forces the conclusion that a part of the work of compression was expended in producing the rise in temperature noted; and furthermore, it becomes painfully evident that this heat increment of work is, so far as the compression process is concerned, wholly lost. In other words, when the air during compression is allowed to heat itself, more power is required to produce a given volume at a given pressure than would be necessary if it were possible to keep the air cool throughout the process. In the first case, there would be adiabatic compression; in the second, isothermal compression. This is a very brief, very elementary statement of the phenomena which give rise to the problems which have confronted the designers of the modern air compressor.

It will have been seen from the foregoing brief discussion that the fundamental problems of pneumatic science are thermo-dynamic in character. The production of heat in compression is unavoidable. The solution of these basic problems, therefore, lies in the removal

or neutralization of this heat of compression before it can have any effect on the air volume. This cannot be done completely, since no perfect and instantaneous cooling device is known. Scheme after scheme has been tried and found wanting, until to-day two general systems alone survive and are accepted by the designers of compressed air machinery. In combination, they attain the nearest approach to the ideal which, as has been seen, is isothermal compression.

First of these two—by right of seniority if not of effectiveness—stands jacket cooling. The barrels and—in the best air compressors—the heads of the compression cylinders are surrounded by a water space or jacket through which an adequate supply of cold water circulates, the waste water carrying away that portion of the heat of compression which is conducted from the air volume through the metal walls. A possible use of this heated water has already been suggested. Water jacketing is useful, but not adequate. It is useful; first, because it prevents the cumulative effects of the heat of compression which would quickly destroy all lubricants and result in injurious expansion strains in the metal of the machine; second, because it keeps the temperature of the air admission passages and valves low, thus admitting cooler air to the cylinder—and every reduction of 5° in intake temperature is equivalent to an increase of 1% in compression efficiency. Water jacketing is not adequate; first, because air is a poor heat conductor and though the outer film in contact with the cylinder walls is cooled, the heat from the interior of the air volume remains; second, because the advancing piston continually covers up more and more of the cylinder walls and the cool area exposed is continually reduced until, just when the highest temperature is attained at point of discharge, only a small fraction of the total cooling surface is in contact with the compressed air. The jacketing of cylinder heads as well as barrels in the best compressors of to-day improves but does not wholly obviate this defect.

The second accepted system of cooling is that secured by stage compression. In this arrangement, instead of being confined to a single cylinder (or parallel duplex cylinders), the compression process is subdivided between two or more cylinders. In the first and largest, air at atmospheric pressure and temperature is admitted and compressed to a moderate pressure and temperature. This compressed air is discharged into an intercooler where its temperature is reduced, by circulation over and contact with water-cooled surfaces, to almost that of the cooling water—perhaps really lower than atmospheric temperature. From the intercooler, this cool and moderately compressed air enters a second cylinder and is compressed to a higher pressure. In a two-stage compressor, this completes the process; in three and four stage machines, the process is continued in a third, or a third and fourth, cylinder. Correct design so proportions the cylinder diameters that the load on all pistons is equal and the maximum temperatures in all cylinders should under such conditions be approximately the same, since this is a function of the number of compressions and not of the initial pressure.

It may be said in passing that in the early days of pneumatic science a third system of cooling was tried—the injection of water in a spray into the compressing cylinder in front of the piston. It may be interesting to note here that this was one of the first types of compressors built by the Ingersoll Rock Drill Company—one of the originals of what is now the Ingersoll-Rand Company; and some of these old machines are still in use today and doing good work. Their compression economy was as high as, if not higher than, that of the most refined modern types. But they were costly machines. The presence of water in the cylinders enforced a low piston speed and, to secure any great capacity, a machine so large was required as to offer serious objection to their wide adoption. Moreover, the proper regulation of the injection of cooling water under varying loads was a delicate problem. Practical difficulties were found to more than offset their high efficiency, and the type was discarded.

Returning to the question of stage compression, the success of the multi-stage system of air compression depends more upon the efficiency of the intercooler than upon any other one thing. For the primary object of stage compression is the reduction of the power required. There are other advantages which will be mentioned later, but at this point a comparison of the gains by compounding will show strikingly the economical advantage. Assume a volume of 100 cubic feet of free air which is to be compressed to a pressure of 100 lbs. gauge. Were perfect isothermal com-

pression possible, this would require 13.17 horse power to accomplish the work indicated. Average single stage compression, which may be considered as practically adiabatic will call for 18.0 horse power. Two stage compression will demand 15.4 horse power; three stage, 14.6 horse power; and four stage, 14.2 horse power. As compared to isothermal, then, the efficiency of single stage compression in this case is 73.2%; of two stage, 85.5%; of three stage, 90.2%; and of four stage, 92.7%. These are purely theoretical considerations. As a matter of fact, two stage compression should be used in this case. For, while theoretically there is undeniably a higher saving in three and four stages, the added complication of design in the increased number of cylinders, valves and working parts, with complex coolers, might so increase frictional losses as to offset the gain; and it would certainly add to cost of maintenance.

The experience of the best builders of compressors has determined the following limits for pressures in different stages; single stage, up to 100 lbs.; two stage, 75 to 500 lbs.; three stage (straight line), 500 to 2500 lbs.; three stage (duplex), 500 to 1500 lbs.; four stage, 500 to 3000 lbs. The real difference in economy between three and four stage compression is often so small as to make a choice difficult. As a general rule, it may be said that three stage straight line compressors should be used for comparatively small capacities; for moderate and large air capacities, its balanced features and its ready adaptability to steam compounding recommend the duplex type. A three stage duplex will still require four cylinders, hence the process might as well be divided into four stages, with no increase in working parts.

The design of these high pressure machines offers peculiar difficulties. While the temperatures attained are not excessive, the great reduction in volume has made the problem of adequate cooling unusually difficult. But before considering this specific phase of the subject, it will be well to take up the general subject of intercoolers.

The successful intercooler, looked upon simply as a heat-removing element, involves several important considerations. It must provide for a very complete subdivision of the air volume, that internal heat may be dissipated with as little reliance as possible upon the heat-conducting properties of the air itself. It must present an adequate cooling surface to this subdivided air; and it must provide for a circulation of cooling water not only rapid and free, but also properly directed in relation to the flow of air. The first two considerations are met by the same means, viz., by the use of a nest of tubes through which the water flows, and over, about and between which the heated air circulates. Properly disposed baffle plates enforce the travel of the air back and forth across, instead of merely along, these tubes. The air must be outside, not inside, the tubes; otherwise each tube will contain a column of air, only the outer film of which will be cooled, the interior retaining its heat. The third consideration is met by causing the air to flow in the opposite direction to the water. This is found to give higher efficiency and greater rapidity of heat absorption. A fourth consideration ought also to be mentioned, as effecting the thermal efficiency of the intercooler. This is the necessity for ample cross-section in the intercooler passages, that the travel of the air may be slow and the contact with cooling surfaces prolonged. Some modern compressors, while having plenty of cooling surface, have the tubes so closely bunched and the intercooler shell so small that the air velocity in transit destroys the thermal efficiency.

Considerations merely mechanical in the correct design of an intercooler are none the less important. Expansion and contraction must be provided for; otherwise there results either a leakage of air and a proportionate waste of power, or a leakage of water into the air chamber, which may be carried over into the next cylinder. This suggests a very important point, viz., the proper drainage of the intercooler. The lowering of the temperature of the air condenses the entrained moisture. If this is not removed at proper times, it will accumulate over the lower tubes, reducing the cooling area as well as the air passage. But the greatest danger is that this accumulation of water will be caught in the sweep of air and carried over in a mass into the high pressure cylinder; and a broken cylinder head, bent piston rod, or other disaster will result.

Evidently such an intercooler as has just been described, while perfectly suitable for two stage compression, or even three where the air volume is large, is not practical with

the small air volumes involved in the later stages of high pressure compression, particularly in machines of small capacity. But long experience and good engineering have solved the problem with success. The method adopted is the complete submersion of the intermediate and high pressure cylinders in water boxes filled with circulating cold water. In this way every inch of metal exposed is a cooling surface; valve caps, air heads, ports, and cylinder walls—all are kept cool, while intercylinder cooling is secured by novel devices. It will be enough to describe one which experience and careful test have shown to be most effective and efficient—the "annular space" intercooler. It consists of two concentric metal cylinders, as thin as the pressure will permit. Their difference in diameter is such as to leave a thin annular space between them, through which the heated air from the intermediate cylinder must pass, spreading out in a thin film between two cold metal walls. The coldest entering water is discharged in the interior of the inner cylinder, and flows thence into the water box in which the intercooler, as well as the compression cylinders, is immersed. The discharge pipe from the intermediate cylinder to the intercooler is entirely submerged, itself acting in some degree as a cooler.

High pressure compressors are no longer "freak" machines, unreliable and largely experimental. The increasing use of high pressure air has demanded a solution, once for all, of the problems of high pressure compression; and the pneumatic engineer has been equal to the task. The best thousand pound pressure compressors of to-day are as reliable, as efficient, as thoroughly "standard," as the lower pressure machines.

It was mentioned earlier in this paper that there were other advantages than increased economy to be gained by compound or stage compression. They are well worthy of consideration in their effect upon ultimate economy and will be briefly discussed here.

The mechanical structure of a machine must be adequate to the maximum strain upon it. This predetermines the minimum amount of material in it. But the endurance of that machine depends upon its factor of safety; and good design demands that this be kept large, with the minimum amount of metal used. In other words, while the maximum strain must be provided for, the average strain must be kept well below the maximum, if the machine is to operate well under long and continuous service. Compound air compression reduces the structural strains in the compressor, resulting in a higher factor of safety and longer life for the machine, with a given weight of metal. In a single stage compressor, the piston starts against no resistance but rapidly builds up a pressure to terminal maximum; and this is maintained until it is instantly relieved by the opening of the intake valves. A 24-inch piston compressing to 100 lbs. gage, single stage, encounters a total resistance of 45,239 lbs. or nearly 23 tons; and at 90 r. p. m. this is encountered and relieved 180 times each minute. It will take the best of metal and plenty of it to stand up under such service as this. But let this same work be done in two stages. The maximum pressure on the low pressure piston will depend upon the cylinder ratios. The pressures in the high and low pressure cylinders will, moreover, partially balance and equalize; and it is found that as a matter of fact, the maximum strain in the machine is reduced to only 55 or 60 per cent of the maximum in single stage compression—in the example cited, from 4140 "ton minutes" to 2277 or 2484 "ton minutes." These are impressive figures and suggest almost unlimited possibilities in the way of improved operation and longer life. This difference in pressures is felt not only in the machine structure, but also in the valves, which must always be considered the most vulnerable, as well as most vital, detail of the compressor. But—and here is a vital point too often overlooked by the designer—this maximum strain of 4140 ton minutes must still be provided for in the machine structure. For the momentary failure of cooling water supply, or the breaking of a high pressure discharge valve may at any moment throw this full high pressure load on the low pressure cylinder. When this happens in a compressor designed only for compound strains, there is nothing to be done but sit down and figure the damages. The engineer or manager contemplating the purchase of a compound compressor will do well, when it comes to a comparison of prices, to figure the comparative costs per unit weight; and, other things being equal, he should give his order to the builder of the heavier machine, whose price, figured on this basis, will not seem so unreasonablly high. But there are, unfortunately, builders who, alive to this fact, give list weights on their machines higher than

strict honesty would permit; and the only safety for the buyer is in the insertion of a penalty clause in his contract, based on the actual net weight of the compressor. This will protect him against over-enthusiastic and imaginative manufacturers.

Another advantage of compound compression lies in the improved steam economy if the machine is steam driven. The conditions just cited in the previous paragraph explain this. It was seen that the terminal strain on the machine, and therefore the terminal power required, was reduced by compounding 55 to 60 per cent. Manifestly this permits a lower mean effective pressure in the steam cylinder, secured by a shorter cut-off, since the power required at the end of the stroke is so much reduced. More of the work of "passing center" may be entrusted to the energy of the flywheel, instead of being provided for by a late cut-off. The mechanical features already mentioned permit also a higher piston speed, improving the steam economy by reducing leakage and condensation losses.

Compounding the compressor also has an important bearing on the volumetric efficiency of the machine—a fact which is due to three causes. As effecting volumetric efficiency, the clearance in only the low pressure or intake cylinder need be considered. In the single stage machine, clearance air at end of stroke may be at a pressure three or four times that which exists in the intake cylinder clearance of a compound compressing to the same pressure; and on expansion it will occupy a proportionally larger portion of the cylinder, before free air can enter. Further than this, the terminal temperature is lower in the compound intake cylinder than in the single stage. Cylinder heads and walls, valves and ports are thus kept cooler, and the incoming air is not so much heated. Further, leakage past pistons and valves is less in the compound than in the simple machine, since the difference in pressure is less.

At this point a slight digression may be permitted. The indicator diagram of an air cylinder is a reasonably accurate record of pressures; but it is wrong to base any estimate of volumetric capacity upon the air card. When the inlet valves open, air rushes into the cylinder and fills it. If the air enters through heated ports, it is itself heated and expanded—and the volumetric capacity of the compressor is accordingly reduced. There is too pronounced a tendency toward valuing a compressor by the card it shows. This is but one of the ways in which an apparently excellent card may in reality hide a true state of affairs directly opposed to high economy.

It may be almost unnecessary to suggest the advantage of compounding in its relation to improved lubrication and, to this extent, in its effect upon the life and operation of the compressor. The terminal temperature in a cylinder being a function of the number of compressions in that cylinder, the high temperatures of single stage compression may result in the charring of the lubricant into a gritty or gummy substance which, accumulating in valves anl passages and on cylinder walls, results in excessive friction, added power and lowered efficiency by leakage.

Still another gain by stage compression is in the dryer air delivered by the compound machine. It developed in the discussion of the intercooler, that that device, properly designed and drained, was an effective dryer and moisture trap. But it is only one link in the system of withdrawing water entrained in the air. The importance of removing the moisture from compressed air is becoming more generally appreciated under the present tendency toward larger units, and longer and more complex air transmissions. In long pipe lines carrying large volumes of air, moisture, if present, will accumulate in the low places in the line and will ultimately fill the pipe, shutting off the passage until the air pressure forces the water up and overcomes the resistance. The writer, in going over the pipe line of a large contract plant in Pennsylvania, was attracted by a periodical rush of water through the 8-inch pipe. Following the line to the next low place, he found a 1-inch drain pipe. Opening this, it took eight minutes by the watch to draw off the accumulated water, which had been rushing up and flowing back repeatedly. Yet he was assured by the foreman that that place had been drained less than two hours before. The plant in question was made up of single stage compressors, with no coolers whatever. Aftercoolers would have prevented this trouble.

Now, this illustrates a point of vital importance in its bearing upon transmission line efficiency. Going further, to the machine using the air, it is unnecessary to dwell upon the trouble and delay caused by the freezing up of exhaust ports, due directly to the pres-

ence of moisture in the air. Occasionally the builders of compressed air machinery meet a situation which forces them to the belief that the real cause of freezing at drills and air motors is not fully appreciated. There is often a mistaken idea that it is the atmospheric termperature which causes this. On the contrary, the writer has seen rock drills freeze tight at midday in the torrid August sun of central New Mexico. The fact of the matter is that the cold is produced directly by the expansion of the exhaust air. It was seen that the compression of air, by a molecular action, produces heat. The exact reversal of this molecular action, in expansion, produces cold. Naturally the trouble is exaggerated in winter weather. But if the moisture is removed from the air before expansion, no air motor can freeze up however high the degree of expansion, for the very simple reason that there is nothing to freeze. In a great quarry plant of northern Ohio, rock drills are operated in the open air with the thermometer far below zero, with not even a suggestion of vapor at the exhaust. But the compressor intercooler is not wholly adequate to this problem of air drying. At best it can remove only a part of the moisture in the air. There must be some further arrangement for air drying; and this leads naturally to a discussion of aftercoolers.

The aftercooler is in essentials identical with the intercooler. Its efficiency is determined by the same conditions; in fact, in compressors of duplex type, the intercooler and aftercooler may be identical in design and capacity. Aside from removing the evils of water in the transmission line, with increased frictional resistance and liability to freeze up in winter; and aside also from avoiding the trouble with "frozen" air motors, the use of an aftercooler is important in its effect upon the life and operation of the motors themselves. Water is not a good lubricant; equally axiomatic is the fact that oil and water will not mingle. The actual fact is that the delivery of water to a drill or other air motor washes out the lubricant, increasing the wear and reducing its effectiveness. Especially true is this in the case of pneumatic tools, where a light lubricant is used. The use of moist air in an expansive engine is practically impossible—a fact largely responsible for the ill-repute of the air motor. Complete aftercooling makes this possible in many cases.

Of value no less important in the air power system is the effect of aftercoolers upon the transmission line efficiency. Nothing will destroy air plant efficiency more quickly and effectively than a leaky pipe line; and nothing is so conducive to a leaky line as wide extremes of temperature, with consequent large strains of expansion and contraction. Without an aftercooler, air from the compressor enters the pipe line hot; the line itself is cold. There is an immediate expansion which extends along the line with continued operation. Now, when the air plant is shut down—probably at night—there is a corresponding contraction all along the line. There needs no voice from the tomb—or elsewhere—to dilate upon the resultant difficulty in keeping tight joints and preventing leakage, even with the best mechanical precautions in the line. The aftercooler is not a luxury; it is an economical necessity in the high-grade air power plant.

The Cleveland Stone Company, at their quarry at North Amherst, Ohio, have an air power plant which is probably without a peer as an example of refined pneumatic engineering. The transmission lines in this system aggregate miles in length and the power is used in drills, channelers, pumps, hoists, mill engines and steam shovels. While reheating is now employed on all but the drills, it was not originally used; yet the engines were for some time worked on short cut-off, and in the midst of a cold winter no trouble was experienced with freezing of lines or motors. The remarkable result is explained by the exceptional precautions taken to provide dry air; and a brief description of the methods employed may not be out of place here.

In the first place, the air enters the compressors through "air washers," which enforce its passage downward through tubes and then upward in bubbles through a body of cold water. This removes from the air the all-pervading dust and grit of the quarry, and incidentally dries it somewhat by lowering its temperature and condensing some of the moisture. Leaving the low pressure cylinder, the air passes through an intercooler, thence to the high pressure cylinder and thence to an aftercooler. From this it goes to very large primary receivers from which the transmission lines radiate; and at intervals along the lines are secondary receivers set *below* the pipe grade. Moisture is first withdrawn from the air in the "washer;" and then in turn in the intercooler, the aftercooler, the primary

receivers, and the secondary receivers. The result is the delivery of absolutely dry air to the motors and maximum pipe line efficiency under all weather conditions, though the lines and the machines are all out-of-doors and unprotected.

More remarkable still, the miles and miles of pipe line have not a single leak. On the contrary, they hold working pressure over night; they were installed under a guarantee to hold full pressure for twenty-four hours. Much of this, of course, is attributable to fine workmanship and studied design, But more than these is it due to the uniform temperature maintained by the use of efficient aftercoolers, with consequent freedom from excessive expansion and contraction strains.

Coming now to consideration of the mechanical design of air compressors, it is found that accepted practice divides these machines into two great fundamental classes—straight line and duplex. The changes which can be rung on variations of these two designs are almost infinite. But analysis will reveal a difference only in detail. The basic principles upon which the designs rest are the same in all.

The straight line air compressor may be considered the pioneer type. The term "straight line" is one of the happy expressions of mechanical phraseology, for it carries with it its own explanation. Its fundamental and distinguishing characteristic is the fact that power is directly applied to resistance. This at once implies simplicity, lack of complication, absence of many parts with undue power consumed in friction. All this results in a machine of high mechanical efficiency and reliability under continued hard service. Its simple design renders it especially attractive for conditions which afford only unskilled attendance. There can be no more sturdy and dependable compressor than the good modern straight line. The compressors examined in the tests reported above belonged to this class; and the figures there set forth show that this type leaves little to be gained in volumetric efficiency. This is a condition, moreover, which is practically constant at all speeds. The main difficulty with the straight line compressor develops in the steam end.

Variable cut-off steam valves give good steam economy at or near normal speed. But the inherent characteristic of the design—the direct opposition of power and resistance—produces conditions which offer serious objections to the straight line machine under widely varying load. In the cylinders, steam pressure falls as air pressure rises; and the flywheels must be relied upon wholly to carry the machine over dead center. This is all very well at high speeds; but reduced load calls for a reduced speed, else there will be a total waste of power by the escape of air at the relief valve. At low speed the energy in the flywheels is not sufficient to pass the center, if the cut-off is short. Cut-off cannot be automatically varied with load, as in a Corliss machine; and to avoid entire stoppage on light load, either the cut-off must be lengthened to give sufficient power to pass centers, in which case there is a waste of steam when the machine speeds up under returning load, or there must be a fixed point below which speed must not fall, in which case there is a blow-off of compressed air at all loads below this limit. These facts force the somewhat unpleasant conclusion that the straight line compressor is not economically self-regulating at less than 35 or 40 per cent. of full load.

This condition practically forbids the successful compounding of the steam end of a straight line. For the high expansion, which is the secret of compound economy, only exaggerates the difficulties at fractional loads. The "double-compound" straight line compressor is practically a constant-speed machine, its economical cut-off admitting of no variation. At normal speed it gives good economy; but underloaded the waste of air at the relief valve simply offsets its normal advantage.

But the straight line compressor is not to be wholly condemned. It remains to-day—and justly so—the most popular machine for plants of moderate capacities using moderate steam and air pressures and working under fairly constant loads. These are the very conditions characterizing the majority of cases in which compressed air is used; and they are conditions in which high steam economy is less important than moderate cost and thoroughgoing reliability.

The second great class of air compressors is that broadly designated as the duplex type. This is not the place for a minute investigation of structural strains and theoretical considerations. For the present purpose it will perhaps be best to look at the duplex compressor as simply two straight line machines set side by side and coupled up for mutual assist-

ance. Seen in this light, the duplex is found to possess all the advantages of the straight line, with the addition of some very important superiorities distinctly its own.

The first of these superiorities lies in the matter of regulation. Quartered cranks permit one steam cylinder to help the other when it most needs assistance; and, a quarter of a revolution later, this favor is reciprocated. The arrangement admits of no "dead center;" and a good duplex will run so slowly at highest loads as to barely turn over, speeding up instantly, however, with increasing load. Best of all, it does this without any change of cut-off; and whether the speed be high or low, steam is always used economically.

But it is as a "double-compound" compressor that the duplex stands without a peer; for in all probability high steam expansion in compound steam cylinders will effect a saving three or four times that secured in stage compression. In the first place, either steam or air end can be compounded without any increase in the number of parts. More than this, the reciprocal cylinder arrangement secures the full advantage of compounding *over the entire load range.* The fact—peculiar to air compressors—that the load per stroke is constant regardless of speed makes a "double-compound" air compressor as completely self-regulating as a simple machine. There will be a slightly increased condensation at lower piston speeds; but the fact that friction loss is a function of the speed and diminishes with it, introduces a saving about offsetting the increased condensation loss at low speed. For these reasons the steam consumption of a double-compound duplex is very nearly proportional to its load.

As compressed air enters more and more largely into industrial activities, the size of plants and units increases, and the demand for economy grows more imperative. It is this condition of affairs which is bringing the duplex compressor into ever-increasing prominence and popularity. It is recognized as distinctly the machine for high grade permanent plants of moderate or large size, using modern high steam and air pressures, operating under widely varying loads and under conditions which make economy of fuel and water essential.

An extended discussion of the subject of air compressor valves is out of the question in such a paper as this. Volumes could be written upon it. It will be enough here to briefly review the essentials of a correct air valve. It may be safely left to the intelligence of the audience to draw just and adequate conclusions as to the merits of any particular valve they may have in mind.

The air intake valve will logically receive attention first. Briefly, its functions are, to admit the full volume of clean, cold air to the cylinder with the least expenditure of power; to keep this air in; and to maintain this performance indefinitely. Analysis of this general statement will develop the facts sought. First, the valve must admit the full volume of air; this demands an instantaneous and complete opening, automatically timed to prevent the escape of air already compressed, and short, direct and unobstructed ports and passages. Second, it must admit clean air, calling for a design which will admit of connection for drawing the air from a place free from dust and grit. Third, the air admitted must be cold; this is partially met by the arrangement necessitated by the second consideration; but more than this, the cold air must nowhere be heated in transit, demanding valves, ports and passages cooled by the jacket water and never called upon for the discharge of the hot compressed air. Fourth, all this must be accomplished with the least possible expenditure of power—a condition demanding few parts and perfect adjustment. Fifth, this valve must keep the air in, calling for automatic and complete closing at just the right time, with perfect seating to avoid leakage. Sixth, it must maintai this performance indefinitely, hundreds of times per minute, demanding simplicity and strength, fine workmanship, and the very best materials.

Similarly, the functions of the air discharge valve are, to release the full volume of compressed air from the cylinder with the least expenditure of power; to keep it out; and to sustain this service indefinitely. This statement also may be analyzed for the essential facts. First, the release of the full air volume calls for automatic timing of an instantaneous and complete opening, and full, free, direct discharge passages. Second, this must be performed at the least cost for power, necessitating few parts and proper adjustment, that friction may be low. Third, the valve must keep out the air it discharged, which means that it must

close instantaneously and completely to a perfect seat at just the right time. Fourth, the continued maintenance of this performance demands simplicity of design, strength of parts, materials of the best quality, and fine workmanship.

It will be noted that the essentials of the successful intake and discharge valve are practically identical, the only difference lying in the necessity for admission of *cold* air through the former. This fact forbids the admission and discharge of air through the same passages. Furthermore it demands that intake and discharge passages shall be separated as far as possible.

It is unnecessary to enter into any extended investigation of the steam end of the steam-driven air compressor. The best engine practice is, broadly speaking, the best compressor practice. But there are conditions in air compression which, in relation to compounding the steam end, seem often not to be well understood.

When steam cylinders are to be compounded it is essential, in order to attain full advantage of expansion, that the cut-off be maintained almost constant at the point fixed by the ratio of the cylinders; for any great change in the cut-off will derange the expansion ratio and prevent the economy sought. Now, in customary engine practice which demands a constant speed, load variations are met by shifting the cut-off; and with light loads the condensation loss due to excessive expansion will make the net saving by compounding questionable, to say the least. Especially is this true where the engine runs non-condensing, and for this reason small and medium sized engines are seldom compounded. But in a correctly designed air compressor of duplex type, governing is done in just the reverse manner, viz., by maintaining a fixed cut-off at point of highest economy and varying the speed automatically with the load. The reasons, therefore, which usually decide against compounding (particularly in small and medium-sized plants) where the steam pressure is low or condensing is not practicable, do not hold with air compressors.

When a new plant is to be installed, including boilers, these can be made for 125 lbs. steam pressure at very little added cost; and this is a very good pressure for compounding. But that peculiar condition of air compression just described, viz., *constant load per stroke regardless of speed*, makes compounding advantageous and economical, all things considered, with boiler pressures as low as 90 lbs. non-condensing, or 75 lbs. condensing. Where boiler water is scarce or costly, or of a bad quality, the reduced amount of feed water required may be added argument in favor of compounding. While where new boilers are to be installed, the smaller boiler equipment permitted by this reduced steam consumption will partly offset the small added cost of the "double-compound" compressor. Cut-off of one half in compound cylinders will give the same expansion as cut-off of one quarter in a non-compound; and it is easy to see that this fact gives to the compound advantages wholly in addition to mere economic gains, in the reduced load on valves and valve mechanism, reduced leakage, diminished clearance evils, lowered condensation losses, improved lubrication, and diminished wear and tear.

In all this it is to be remembered that compressor practise is unique in that while the speed varies with the load, the load per stroke remains constant at all speeds. Power, therefore, remains constant per stroke, and all the advantages outlined above are fixed in their values regardless of load.

The regulation of steam driven compressors need not be discussed here. The methods employed are too well known. But the principle, whatever the device employed, is the same in all—a variation of speed to change the displacement to meet varying demands for air. But when some other power than steam is the prime mover of the compressor, other means of governing must be used. And this leads naturally to the subject of power driven air compressors.

The power driven air compressor is essentially a constant-speed machine. Since its actual piston speed and therefore displacement cannot be changed, the only means of adjusting the volume of air compressed to the demand lies in making ineffective a portion of the displacement. But evidently economy forbids blowing off superfluous air through the relief valve. There are three general methods of "unloading" a compressor. One is by opening, at light loads, a passage from the intercooler to the atmosphere, discharging the low-pressure air until load is re-

sumed. This is simply a waste of power—yet better than blowing off high pressure air. Another method is by automatically holding open one or more discharge valves at both ends of the air cylinder, which balances pressures on both sides of the piston and removes all but the friction load. This is a very complete and positive unloader—and therein is its only objection. If the unloaded piston is traveling under balanced pressure of 100 lbs. on each side, and load is resumed at any point of the stroke, on the return stroke the piston must displace a full cylinder of air at 100 lbs.; in other words, the load during this return stroke is three or four times the normal maximum. This overload, moreover, is instantly thrown on the piston, held throughout a stroke, and is instantly relieved; and this sudden, positive assumption and release throws strains on the machine structure which limit the use of an unloader of this type to compressors of comparatively small capacity. The third method of regulation is by limiting or varying the compressor intake—and this comes very near being a solution of the problem. Receiver pressure controls a valve in the free air intake, throttling it when load is light, opening it as load increases. An oil damping device makes the unloading and loading gradual and perfectly safe in all capacities. But this device is not without its draw-back. As the intake is throttled, the air admitted to the cylinder becomes rarified, and on return stroke, though the free air volume is small, the range of pressures is so much increased that terminal temperatures may soar to destructive heights. This style of unloader, therefore, is not wholly adequate where the load variation is very great; and the difficulty increases with the terminal pressure.

In the regulation of the power driven air compressor plant, less reliance must be placed upon the automatic regulation of the individual machine than upon the intelligent sub-division and management of the plant itself. The old-time truism about the folly of putting all the eggs in one basket has become so polished by use that it is to-day really a gem, nowhere more apropos than in the modern pneumatic power plant with power driven units. At the outset it must be remembered that the power driven compressor has no overload capacity, *i. e.*, an overload of volumetric capacity or piston displacement. In the installation of a plant made up of these units, therefore, the maximum capacity must be provided for in the normal output of the machines. Yet fractional loads must also be provided for; and here the designer is confronted with another inexorable condition, viz., the power driven compressor unit is a constant-speed machine.

It may be remarked here that in 90% of the installation of power driven compressors, either electricity or water power will be the prime mover; and of these, probably 80% will be electric driven and the remainder water driven. It will be safe to consider the case of the electrical compressor as typical, since the deductions will apply almost equally well to those driven by water motors.

The electric motor has its maximum efficiency under continuous running at its full load rating. Below that, efficiency falls away. Plant economy, therefore, forbids underloading the electrical compressor unit to any great extent. But in all probability the load curve of the plant will vary widely. Since the individual unit cannot be relied upon for economical regulation, the only solution of the problem lies in the sub-division of the plant into units, of suitable capacities to be determined by the character of the load. This subdivision should be such that the greater variations could be provided for by cutting out one or two or more units, the others meanwhile continuing to run at or near full load. A theoretical case may best illustrate the principle.

Assume that the problem is to install an electrical air power plant which is to work under load variations of from 500 horse power maximum to 75 horse power minimum, with a normal of 400 horse power. The proper solution, in order to get the best economy possible, would be the installation of three motor-driven compressor units; two of 200 horse power and one of 100 horse power. The smaller unit would have an automatic unloader, preferably of the third type mentioned. The possible combinations of this plant would be 100, 200, 300, 400 and 500 horse power, under all of which the motors and compressors would be running at maximum efficiency. When the load fell below 100 horse power the unloader would safely and economically care for a reduction of 25 or 30%. Such a plant could be made very largely automatic by the

use of automatic relay starting-and-stopping controllers, in which the governing valves are adjusted to work in proper rotation under slightly different variations of pressure.

This in briefest outline is the system of unit plant design. It requires an intelligent adjustment of operating conditions to smooth out the load curve as far as possible. But it offers a full solution of the problem of economical management of a large power driven compressor plant under varying load. This is a point at which electrical and pneumatic practice meet, and the difficulties involved are well worthy of the best talent in both lines of engineering.

The gas engine driven air compressor is to-day largely an unknown quantity. In small units, for portable work or other purposes requiring only small capacity, it has been successfully built and operated. But in larger sizes it is still largely in the experimental stage. The problems involved seem not to be beyond solution, and they are already well understood. But there has not been enough demand for this class of machines to develop an experience which can be safely relied upon. If, as is sometimes said, the gas engine is the prime mover of the future, it behooves the pneumatic engineer to face the problems of gas engine compression. But as yet the occasion has not arisen; and pneumatic engineers to-day find quite enough to occupy their attention in other lines.

The second of the three general divisions adopted in this paper comes now for discussion.

The phenomena of air expansion are governed by the same laws as those of air compression. Boyle's and Gay-Lussac's Laws of thermo-dynamics express the relations of pressure, temperature and volume. In fact, the theory of the application of compressed air may be best understood by considering expansion simply as a negative compression process. Isothermal expansion is expansion at constant temperature, *i. e.*, no heat is lost. It is an impossible ideal, whose value can at best be only approximated. Adiabatic expansion is expansion with a total proportionate loss of heat; and it, too, can be only partially realized.

Were isothermal expansion possible, the expansion of a given quantity of air to one half its original pressure would give a volume just twice as large as the original. As a matter of fact, in practice the volume will not be doubled when the pressure is reduced one half. For the expansion, reversing the molecular action of compression, results in a lowered temperature which contracts the air volume , according to Gay-Lussac's Law.

As, in adiabatic compression, there is a loss as compared to isothermal due to the *positive* heat increment of work, so, in adriabatic expansion, there is a loss as compared to isothermal due to the *negative* heat increment of work. There is, therefore, in adiabatic compression and expansion a double loss of energy. It was shown that the loss in compression can be reduced, but not wholly avoided, by removing the heat of compression as fast as produced. So, in air expansion, the loss may be diminished, but not obivated, by "removing the cold," *i. e.*, by heating the air during expansion. With this elementary theoretical sketch, the subject of reheating may be taken up.

Evidently it is impossible to heat the air in an expansive engine *during* expansion. But the same effect may be secured by heating the air before it enters the cylinder, thus giving it an excess initial pressure such that the expanded volume will be normal and at normal pressure. If heating is carried only to this extent there is no positive gain, but simply an avoidance of an otherwise inevitable loss. But this is by no means the limit of the possibilities of reheating.

Gay-Lussac's Law states that, at a given pressure, the volume is proportional to the temperature; which means that reheating is equivalent to an increase of volume at that pressure. Or, looked at from another viewpoint, reheating a given volume of air will increase its pressure. In either case, reheating results in a positive increase in the available energy of the compressed air.

With single cylinder or duplex air engines, preheating only is practicable; and it results in securing the same mean effective pressure in the cylinder with a greater degree of expansion and therefore with a greater economy of air. But compound air engines, such as may be used on pumps or hoists, permit both preheating and interheating. This is "stage expansion" and is the exact reversal of "stage compression."

The limit to which reheating may be car-

ried seems to be fixed only by the endurance of the materials exposed to the high temperatures; more especially, by that of the lubricant used in the engine cylinders. But where an oil of high flashing-point is used, the temperatures which may be applied are surprising; for while the initial temperature may be very high, the wide range of expansion results in a mean cylinder temperature which is within reasonable limits and wholly practicable.

The reheating of compressed air offers the most inviting field for pneumatic research to-day; and it is a field which is only beginning to be explored. Facts and figures are singularly hard to get hold of. While many types of reheaters are on the market, the wide variation in capacity ratings shows that even the builders are not at all certain of their ground. But there is an awakening in progress. All other pneumatic appliances are nearing the limit of mechanical and economical refinement. Compressed air is reaching out beyond the small mine or shop plant into the vast field of general power transmission on a large scale. The rock drill and pneumatic tool do not use air expansively, nor is their mere air economy a fair measure of their value. But for pumping, hoisting and general industrial use as a motive power, in units of any capacity, expansion must be employed if any degree of economy is sought. The great companies who are to-day the leading exponents of air power are alive to the requirements of the situation. Their engineers are grappling with the problems of reheating with the same skill and energy which have been brought to bear along other lines of pneumatic development. When compressed air reaches a condition of advancement where the very highest economy of application is essential, the builders of air power machinery will be ready with reheaters of the same reliability and efficiency which mark the other pneumatic appliances of to-day, placing them in a class distinct and unique among the mechanical developments of the past hundred years.

It was suggested to the writer that in this paper there be embodied a comparison of compressed air and electric power. But an evening could be devoted to that subject alone without doing it justice. It may be said, however, in closing, that the rivalry between compressed air and electricity is more imaginary than real. A few years ago, perhaps, each viewed the other with suspicion. But in this age of tremendous industrial development and inexorable sifting-out of non-essentials, all things worthy of survival find their proper place. It has been so with compressed air and electricity. Each has a field distinctly its own, into which the other can not hope to enter with any prospect of success. At points these fields touch or even overlap; but even here, instead of bitter rivalry, there is a mutual recognition and a cordial co-operation.

When compressed air and electricity *do* join forces, the result is apt to be spectacular, from an engineering standpoint. Where can be found a greater masterpiece than the electro-pneumatic switch and signal system of the New York Rapid Transit Subway, in which the electric current throws the valve admitting the sturdy power of compressed air from automatic air compressors driven by electric motors? Or what can be more striking, more simple or more absolutely dependable than the storage air brake system of the St. Louis Transit Company, in which the air from automatic electrical compressors controls the electric cars which carried the hundreds of thousands of World's Fair passengers without a mishap, a break-down, or a delay? A hundred other instances might be cited in which air and electricity—either powerless without the other—have joined hands in a wonder-working achievement; and nothing can prove, better than these great co-operative triumphs, that the days of competitive strife between compressed air and electric power have permanently passed.

AIR MAINS

Pipes supplying air to rock-drills should be of a size to permit the passage of air at a velocity not greater than 25 to 30 ft. per sec., while all bends and angles (especially short ones) should be avoided, as they add greatly to the friction of the air, and thus decrease the pressure. The friction of the air is proportional directly to the length of the pipe, and to the square of its velocity. For this service, pipes up to 5 in. diameter are provided with couplings, above that with flanged joints made up with gaskets. Great care must be taken that these joints are perfectly tight, as the loss, even from a pin-hole, is considerable.

JAMES CLAYTON

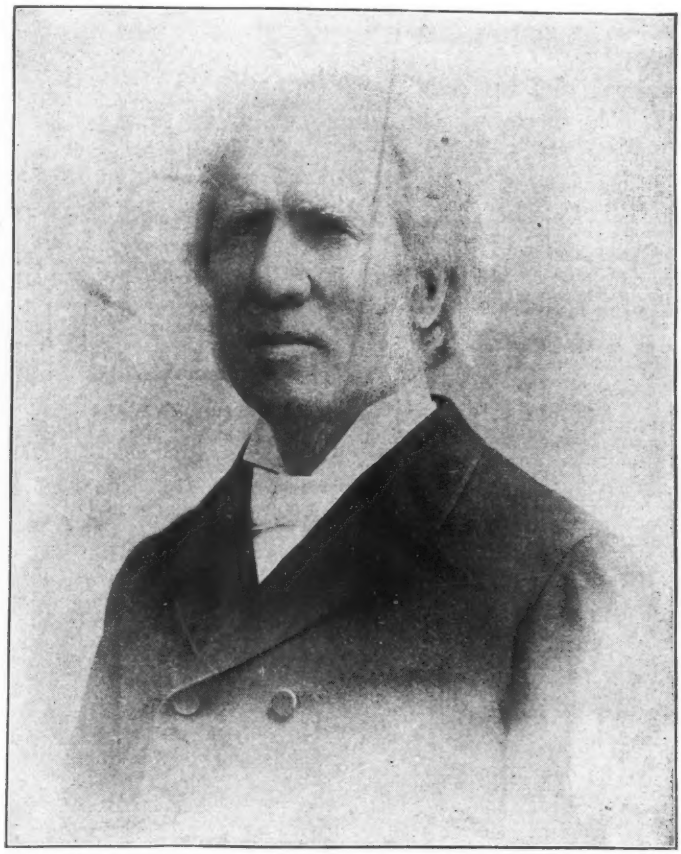
Fifty-seven years ago James Clayton came to this country from his birthplace, Homer, in Shropshire county, England, and became interested in the gold fields of Grass Valley, California.

Between the years of 1864 and 1867 he started in business manufacturing air compressors and pumps.

Always keenly alive to the development of the business which he had founded, he still found time to pursue and successfully complete a number of valuable inventions, such as compressors with mechanically operated valves, an efficient fire pump, the first one having been built for the Long Island Railroad grain elevators, and improvements to a system for pumping water by means of the air lift.

It is interesting to note that among the first compressors built and sold by Mr. Clayton to such concerns as the Copper Queen Mining Co., Plymouth Coal Co., Jamaica Government Railways, and the Highland Mary gold mine, was a machine built for a Dr. Sass to be used in connection with a pulmonary cure.

At the age of eighty-four he is still enjoying a full measure of health, and the photograph which we are privileged to reproduce will doubtless bring back many reminiscences to a number of our readers who are proud to call themselves his friends.



JAMES CLAYTON.

IT is suggested by a trans-Atlantic contemporary that air brakes be used on motor 'buses. It goes on to say that compressed air would also be very useful for other purposes, such as increasing the volume of the gas sucked in on the induction stroke, blowing the horn, and starting the engine.

COMPRESSED AIR

Established 1896.

A monthly magazine devoted to the useful applications of compressed air.

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AIR BRAKES FOR MOTOR CARS

A comparatively new field for compressed air is suggested in an article by Mr. Thomas J. Fay in a recent issue of the *Horseless Age*.

Mr. Fay points out that most automobile accidents are due to one of the three following causes: 1. Lack of judgment of the distance in which a motor car may be stopped. 2. Rupture or deformation of some essential part of the car. 3. Lack of efficient brakes, or brakes out of adjustment. Of these three possible causes the latter undoubtedly is responsible for a considerable portion of the accidents on record.

Air brakes for automobiles may be divided into two distinct types, according to whether they are operated by air pressure or are applied by a spring and released by air pressure. The latter type, therefore, should more properly be termed "air released" brakes and possess the advantage over the former type that, if out of order, the brake would be applied and the car could not be started.

Mr. Fay states that the dimensions of brake cylinders for the heavier type of cars with ample weight on the traction wheels (to which the brake should be applied), should be approximately as given in the following table:

6,000	pounds	.....	5	in.	diam.	x 12	in. long
5,000	"	.....	4½	"	"	x 12	" "
4,000	"	.....	4	"	"	x 12	" "
3,000	"	.....	3½	"	"	x 12	" "
2,000	"	.....	3	"	"	x 12	" "

It is pointed out that it is not necessary to use an air compressor for operating air brakes as the pressure can be obtained from the motor cylinders. This is an important point, as one of the chief arguments against air brakes for use on motor cars has been that the air compressor absorbed a great deal of power; in fact, it has been estimated that the power required to operate the air brakes of a motor car would be approximately one-tenth of the power of the engine which, in the case cited, amounted to 3½ H. P.

It is evident that by using the pressure to be obtained from the motor cylinders the above objection is obviated and the use of air brakes on automobiles will not involve any more complication than are now found in the braking arrangements of most of the large cars fitted with two independent differential brakes and emergency brakes.

A NEW APPLICATION OF THE CHANNELING MACHINE

Not very long ago this paper published an article, entitled "Improvements in the Channeling Machine," in which was pointed out the great saving which could be effected in quarrying and other forms of rock excavation by the use of channelers of the latest type. It may be of interest to our readers, therefore, to know of a recent application of these machines to some special work in New York City. For some years engineers and contractors have been vexed with the problem of removing rock in excavating for new buildings, railway cuts, etc., without disturbing adjacent foundations. To accomplish this by cutting the side walls with track channelers had, up to the present time, been considered impracticable, but the success of channelers for this work on the New York Central cut under Depew Place, has conclusively proved the practicability and superiority of this method.

In a recent issue of *Mine and Quarry*, pub-

lished quarterly by the Sullivan Machinery Company, there is contained a very interesting article by Joseph H. Brown, Jr., describing the work of this company's machine on the above contract. It seems that the work involved in the excavation of Depew Place for its full width of 50 ft. between 42d and 44th streets, a distance of about 500 ft. Below the natural soil and fill, which extended to a depth of 15 to 25 ft., existed ordinary gneiss rock, the stratification of which was broken and irregular. The average depth of rock to be excavated was about 15 ft. and the total amount, approximately, 18,000 cu. yds. On one side of the street, the baggage room of Grand Central Station extended the full length of Depew Place, and upon the opposite side was the Grand Central Palace, 200 ft. in length.

On account of the proximity of the foundations of these buildings to the line of the cut, the contractors found it impossible to blast without first freeing the rock at the side and they determined that channeling machines, operated by compressed air and fitted with air reheaters, would prove the most economical method of making the cut. Accordingly a Sullivan Class Y machine with 8 inch cylinder, using a solid Z-shaped steel, was started to work on June 30th and was operated continuously 24 hours a day in three shifts of eight hours each up to August 1st, the cuts being made in two and in some places three lifts, varying from 6 to 9 ft. in depth.

The progress made was so satisfactory that about August 1st a second machine was installed of the same type, so that the walls on both sides of the street could be channeled at the same time. Mr. Brown states that these channelers frequently cut as high as 10 ft. an hour in the irregular gneiss formation, which proved to be one of the most difficult in which channelers have been made to operate.

In regard to the cost of drilling and broaching by the old method, Mr. Brown estimates it as follows: Assuming that 60 ft. can be drilled per 8 hour shift, 6—10 ft. holes can be put down; and allowing three inches for the diameter of the hole and one inch for the rib between, 20 sq. ft. will be drilled per 8 hour shift. Furthermore, it will take at least one-half as long to broach as to drill, or one-half shift.

Drilling costs per shift:

Runner	$3.00
Helper	2.00
Power, oil, blacksmith, etc.	2.00
	7.00
Broaching	3.50
Total cost per 8 hour shift	10.50

Cost per foot, $0.525.

The estimated cost of running a channeler eight hours may be taken at $10, including runner, helper, blacksmith and power. Therefore, averaging 60 sq. ft. per 8-hour shift, the cost per foot was $.16⅔, a saving of $.36 per foot, or 68.3% over the method of drilling and broaching, in addition to cutting the time in half.

It is interesting to note, therefore, that the results fully approved the judgment of the contractors and that the channeler has proved its right to an important place in a contractor's equipment.

COMING EXPOSITION OF SAFETY DEVICES

Last month the press very generally notified the public of the Exposition of Safety Devices which the American Institute of Social Service proposes to hold in New York, January 28th-February 9th, 1907. Gratifying interest is being shown by the inventors and manufacturers of devices for protecting the lives and limbs of workers and of the general public.

Applications for space are being filed in the order of their receipt.

Commissioner General Kohlsaat, alive to the importance of the Exposition to be held in New York, desires to secure it entire for the enrichment of the Jamestown Exposition in 1907.

European co-operation has been generously pledged. The Belgian Minister of Labor has promised a large part of the Belgian Exposition of Safety Devices and Housing.

Dr. Muensterberg, perhaps the greatest European authority on public and private charity, has promised to send for the Section of Industrial Hygiene selected and typical exhibits of santoria for consumptives and also for drunkards, First Aid to the Injured Stations, of Red Cross Stations, of Workmen's Colonies, and other valuable material.

Dr. Hartmann of the Berlin Museum of Security will send a splendid collection of pho-

tographs and hundreds of scale drawings of safety devices.

M. Mamy, Director of the Paris Museum of Security, has already shipped valuable material.

Various influential Europeans are co-operating with the Director of the American Institute to secure the best safety devices from the continental manufacturers.

Prominent Americans also are lending their co-operation as honorary vice-presidents: Grover Cleveland, first vice-president; Hon. Frank W. Higgins, Governor of New York; Hon. Curtis Guild, Jr., Governor of Massachusetts; Hon. E. C. Stokes, Governor of New Jersey; Hon. Henry Roberts, Governor of Connecticut; Hon. C. P. Neill, U. S. Department of Labor, Washington, D. C.; Hon. T. P. Sherman, Labor Commissioner of the State of New York; H. C. Bumpus, Director American Museum of Natural History.

Requests for information regarding space should be made to Dr. William H. Tolman, Director, 287 Fourth avenue, New York.

COST OF RIVETING ON THE BROOKLYN TOWERS AND END SPAN OF THE WILLIAMSBURG BRIDGE, NEW YORK CITY

It is interesting to note in an article by Mr. Francis L. Pruyn, Associate Member Am. Soc. C. E., in a recent issue of *Railway Maintenance and Structures,* the cost of riveting the main towers and end span of the Williamsburg bridge. The riveting was done with pneumatic riveters, from four to eight being generally in use. Four men, including the rivet heater, constituted a gang, each man receiving $3.76 per eight-hour shift. Compressed air was furnished at about 80 lbs. pressure by two compressors, with a combined capacity of approximately 300 cubic feet per minute. The rivets used on the intermediate tower were short and easily driven as indicated by the cost given in the accompanying table, while the heavy sections on the main tower and end span required long heavy rivets which were very difficult to drive. The total cost of the plant was as follows:

Two boilers at 50%	$ 300 00
Two compressors at 50%	1,300 00
Nine pneumatic rammers at 50%	1,800 00
Fifteen forges at 50%	250 00
W. I. pipe	200 00
Coal	1,120 00
Steel, tools, scaffold, etc.	1,350 00
Plant, labor, miscellaneous	2,290 00
Total	$9,610 00

	Main Towers.		Intermediate Tower.		End Span.		Total	
No. Rivets Driven, Net	100,039		18,971		91,835		210,845	
	Per Rivet.	Total.	Per Rivet.	Total.	Per Rivet.	Total.	Per Rivet.	Total.
Total, labor	$0.158	$15,874.00	$0.085	$1,609.00	$0.159	$14,631.00	$0.152	$32,114.00
Labor, scaffolds	.021	2,071.00	.003	64.00	.005	465.00	.012	2,600.00
Plant	.046	4,615.00	.045	865.00	.045	4,130.00	.045	9,610.00
Total	....	$22,560.00	....	$2,538.00	....	$19,226.00	....	$44,324.00
General expenses, at 10%	$0.022	2,256.00	$0.013	254.00	$0.02	1,922.00	$0.021	4,432.00
$0.247 $24,816.00 $0.146 $2,792.00	Total				$0.229	$21,148.00	$0.23	$48,746.00

AIR COMPRESSOR LUBRICATION

Air compressor lubrication has received considerable attention of late in the technical press but not as much as it should. It is a very important subject to users of compressed air and one that comparatively few engineers have paid much attention to. Improper lubrication has been responsible for many accidents and explosions, the seriousness of which is evidenced by the following abstract from the *National Engineer:* "The pipe line leading from the receiver around the shop was not only bursted, but was opened perfectly flat, just as flat as the plate was before the pipe was made. This was small pipe, some 2", 1½" and 1", which should stand at least 15,000 lbs. pressure. The minute the explosion occurred a flame of fire shot out of the receiver. The explosion wrecked the entire roof of the building which shows plainly that there must have been a very heavy pressure. We could not get more than 100 lbs. pressure on the receiver. We feel satisfied that there must have been at least 1000—2000 lbs. pressure to have caused the wreck."

Alexander M. Gow, M. E., writing in the *Engineering News,* states that "excess of lubrication in addition to waste, means increased accumulation of combustible matter, increased lodgment of dust and increased danger of accident. . . . It will not be argued that all the lubrication used in the air cylinder is deposited on the walls of the receiver, but *some* of it will be, and the more lubricant used the more will be deposited. . . . It follows that just as little lubricant should be used as possible, inasmuch as an air cylinder requires less oil than a cylinder of equal size using steam. . . . Two lubricants are in general use in air compressor cylinders, a mixture of soap and water, and cylinder oil. Either can be made to do the work. While ignitions are bad, and must be avoided if possible, explosions are more serious. Evidently they are due to the formation of a mixture of combustible gas or vapor in suitable proportions with air at a temperature sufficient to ignite. The percentage of gas or vapor required to make an explosive mixture is surprisingly small and in general the heavier the gas or vapor the smaller the percentage. . . . *Combustible gas or vapor is evolved from all lubricating oils by heat.* It is by no means uncommon for the engineer in charge of an air compressor to introduce through the inlet pipe a quantity of light oil or even kerosene. This is a favorite and sometimes effective way of cleaning dirty discharge valves. Under such conditions it is possible for an explosion to take place immediately. Such practice is simply tempting Providence and Providence at times refuses to resist the temptation."

Many other authorities might be quoted on these points but those who have had experience in air compression will find these sufficient to convince them of the importance of proper lubrication. It is interesting to note therefore that graphite is coming more and more into general use for this purpose, and we are just in receipt of an exceptionally interesting treatise published by the Dixon Crucible Company, Jersey City, N. J., devoted to the subject of graphite and its application to air compressor lubrication. The arguments which the Dixon Company put forth are very convincing, as this lubricant is inert under high temperatures and therefore eliminates all danger of explosions; furthermore, it fills up any unevennesses, roughnesses and pores in the metal, bringing the surfaces much nearer to a condition "perfect" smoothness, than is possible by any other known means. This effects a material reduction in the "solid friction" between those surfaces, for it is a fundamental principle in lubrication that the smoother bearing surfaces can be made, the less will be the friction between them and the easier will they be to lubricate.

Graphite shows a strong tendency to attach itself to metal surfaces and, when thoroughly worked into the inequalities of surfaces, imparts a superficial glaze, or veneering, of great smoothness, high polish and endurance that prevents actual contact, metal to metal, and makes it possible for relatively small quantities of fluid lubricants to provide a safe and sufficient film or lubricating layer.

Flake graphite may be mixed with oils, soap suds or water for lubrication purposes and there are now on the market several lubricators such as the Graphoil Lubricator for feeding this new lubricant.

NEW PUBLICATIONS

Management of Electrical Machinery.—A revised and enlarged edition of Practical Management of Dynamos and Motors by Crocker & Wheeler. D. Van Nostrand & Co., New York; price $1.00.

This book has long been considered as standard in its field and scarcely needs comment except to call attention to some of the changes which have been made in the last edition. The first chapters on Principles of Electrical Machinery, Selection, Installation and Operation have been revised, and the latter part of the book, referring to troubles with machinery, has had considerable new matter added on the subject of alternating current generators and motors. Furthermore, obsolete types of machinery have been eliminated from the book. The book as now printed is divided into five parts: Part 1, covering Selection, Installation, Connection, and Operation. Part 2, Inspecting and Testing. Part 3, Localization and Remedy of Troubles. Part 4, Constant-Current (Arc) Generators. Part 5, Management of Railway Motors. These five parts occupy 218 pages, with 131 illustrations, and the book should be of great assistance to the operating engineer in explaining the difficulties which he is likely to encounter in handling electrical machinery. It also contains sufficient theory to show the reasons for

the remedy besides giving the theoretical student an idea of the practical side of his profession.

Gas-Engine Design, with an introduction on Compressed Air by E. J. Stoddard, published by Parker & Burden, 1217 Hodges Block, Detroit, Mich. Price, bound in paper, 25c; flexible cloth (buckram), $1.00.

The only part of this book which directly concerns the user of compressed air is the section devoted to an introduction on compressed air, and also the first chapter, which treats of a graphical construction of the curves, $PV^n = C$, which are worked out for various values of n corresponding to isothermal compression of air, adiabatic compression of air, adiabatic compression for gas engine, saturation curve of steam, etc.

The chapter devoted to compressed air treats of the theoretical side only and is exceedingly complete. Aside from the derivation of the characteristic compressed air formulæ, this book contains numerous tables and curves showing volume, final temperature, and pressure in atmospheres corresponding to various gage pressures. It also gives the square root, cube root and fourth root of numbers from .1 to 20.4. Furthermore, a table is included showing the mean effective pressure, work per pound of air compressed and other important facts corresponding to the compression of air from 0 gage pressure up to 200 lbs. per square inch.

The book is ably written and should be a valuable addition to any engineer's library.

TRADE PUBLICATIONS

Note.—We believe it to be the desire of every up-to-date engineer to acquire a comprehensive collection of trade catalogs covering the subjects in which he is most interested. We therefore endeavor to review the catalogs submitted to us briefly, but carefully, in order that our readers may form some adequate idea of their contents and value.

Cyclone Drill Company, Orrville, Ohio.—Eighty-five-page catalog, 6 x 9, fully illustrated, describing their full line of prospecting machinery for coal, water, oil, gas, mineral and placer mining. The catalog describes particularly their portable churn drills and rotary core drills and covers the subjects of sand pumps, drilling tools, blowers and spare parts. Catalog 6 x 9, fourteen pages devoted to Cyclone contractor drills and Economy blast hole loaders. Also catalog 6 x 9, twenty-two pages, covering their drilling machines for contractors and rock excavation work.

Pratt Institute Free Library, Brooklyn, N. Y.—Catalog of books on electricity contained in the Applied Science Reference Room. This room has been lately opened to the public and contains an especially complete assortment of engineering reference books.

Ingersoll-Rand Company, 11 Broadway, New York.—Small booklet, Form 35-A, illustrating and describing Ingersoll-Sergeant air compressors, both straight line and duplex.

C. W. Hunt Company, West New Brighton, S. I.—Forty-four-page booklet devoted to Hunt industrial railways and their equipment. This booklet, while small, is well illustrated and singularly complete.

The Whitaker Manufacturing Company, Chicago, Ill.—Small booklet entitled Modern Tools, and illustrating their line of twist drills, air drill reamers, drill chucks, taps, saw blades, ratchet drills, wrenches, etc.

People's Specialty Company, Corning, N.Y.—Small booklet illustrating and describing the Simplex drawing and time card holder, being a frame for holding blue prints and time cards which may be attached to a lathe or other machine tool in such a position as to be equally seen and read by the machinist. The use of this apparatus does away with mounting blue prints.

Allis-Chalmers Company, Milwaukee, Wis.—Forty-page bulletin (Bulletin No. 1507), 7¾ x 10¼, devoted to a description of the general subject of air compression and to the compressors manufactured by this company. The bulletin contains many valuable tables and other data of interest to engineers and will doubtless be very much in demand.

Hanna Engineering Works, 820 Elston avenue, Chicago, Ill.—Four-page leaflet describing the Hanna radial reamer for reaming rivet holes in bridge and structural girders, etc.

Baldwin Locomotive Works, Philadelphia, Pa.—Record of Recent Construction, No. 59, 34 pages, 6 x 9. This booklet is most handsomely printed and describes and illustrates many of the recent locomotives which have been built by this company.

Ingersoll-Rand Company, 11 Broadway, New York.— Bulletin No. 2011, issued by the Pneumatic Tool Department, and devoted to a de-

scription of the "Little Jap" hammer drill for light work in all rock excavations. The bulletin contains twenty pages, fully illustrated, and is 6 x 9 inches in size.

Sullivan Machinery Company, Railway exchange Bldg., Chicago, Ill.—Bulletin No. 51-D, twelve pages, 6 x 9, illustrating and describing Sullivan pneumatic hammer drills for quarrying and contracting work. The pamphlet is well illustrated and full particulars are given of the drills.

Joseph Dixon Crucible Company, Jersey City, N. J.—Twenty-six page pamphlet devoted to the subject of air compressor lubrication. This pamphlet is particularly valuable to engineers and operators of air compressors as it contains a thorough description of the use of flake graphite for the lubrication of air cylinders.

Chicago Pneumatic Tool Company, Fisher Bldg., Chicago, Ill.—Catalog No. 20, 116 pages, 6 x 9, describing the full line of Franklin air compressors manufactured by this company. Constructive principles are described in detail and information not hitherto published is given relative to several new types of compressors including Corliss, motor-driven, gas engine driven, and new pattern compressors of larger capacities. This catalog also devotes considerable space to the subject of pumping by compressed air, besides including numerous tables and formulæ of interest to compressed air users.

Roteng Engineering Co., 299 Broadway, New York.—Bulletins Nos. 55 and 56, illustrating and describing rotary belt-driven and motor-driven air compressors of a new design. These compressors are very simple in construction and represent an entirely new principle in the design of air compressing machinery.

The Rix Compressed Air and Drill Company announce that they are how occupying their new offices at 219-221 Spear street, San Francisco, Calif., which is their main office and salesroom. Their factory, warehouse, and branch office are located at 1436 Fifth street, Oakland, Calif. They state that their factory has greater capacity than before the fire and that they are now able to fill all orders for air or gas compressors, rock drills, etc.

INDUSTRIAL.

BUTT WELDING WROUGHT IRON PIPES BY THE THERMIT PROCESS

Thermit, as most people know, is a mixture of finely divided aluminum and iron oxide which when ignited in one spot communicates the combustion throughout its mass without the introduction of heat or power from outside and produces during this combustion (in about fifteen seconds), a temperature of approximately 5,400° F.

WELDING A 1¼-INCH PIPE.

During the reaction which produces this heat, the aluminum and the oxygen contained in the iron oxide combine to form a highly superheated liquid slag (aluminum oxide). The iron which is set free at the same time and at the same temperature sinks to the bottom of the containing vessel or crucible.

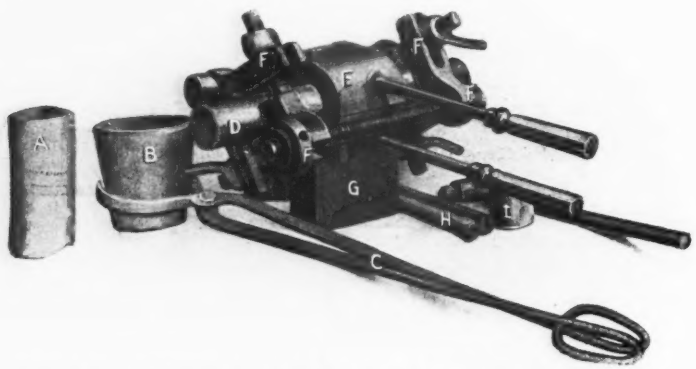
In the case of pipes and small rods, the superheated molten mass is poured around the pieces to be welded, the latter are thus brought to the necessary temperature and the weld is completed by physical pressure as described below.

It is necessary that the ends of the pipe be prepared somewhat for the process of welding and they are accordingly filed and then butted carefully together between clamps. A cast iron mold, in two pieces, is then placed around this

joint, the upper part of the mold having a narrow gate to admit the superheated mass.

The thermit is ignited in a flat bottomed crucible held in a pair of tongs. After the reaction the slag fills the upper part of the crucible and occupies three times the volume of the superheated liquid steel which collects at the bottom after the reaction has taken place.

The superheated liquid mass is then poured into the opening of the mold. The slag flowing first, will adhere in a thin layer to the walls of the mold and the surface of the pieces to be welded and will protect them from contact with the liquid steel which runs in last. After waiting for the ends to soften, the clamps are drawn up and effect the weld by squeezing together the now plastic ends of the pipes. The



EQUIPMENT REQUIRED FOR WELDING PIPE BY THE THERMIT PROCESS.

A, Welding Portion Bag; B, Crucible; C, Tongs; D, 2" Pipe; E, Top Talf of Cast Iron Mould Box; F F F F, Screw Clamps; G, Support for Bottom Half of Cast Iron Mould Box; H, Pins for Screwing Up Clamps; I, Ignition Powder.

welded joints are as strong as the rest of the pipe and, after removing the molds and clamps, the weld will be perfectly solid and there will be practically no upset at the joints. On chilling, the layer of slag is easily knocked off.

An interesting point in the application of this process of welding is the fact that it is adapted to either steam, compressed air or ammonia pipe lines and the joints may be welded anywhere in place and vertical pipes are welded as easily as horizontal.

The thermit powder is put up in bags containing the quantities necessary to weld a given joint which is called a "welding portion." The necessary appliances consist of a set of clamps, tongs, cast iron mold and crucibles. The first two articles are permanent; the molds should last for sixty or more welds and the crucibles will withstand twelve to fifteen reactions. One half teaspoonful of ignition powder is required to start a reaction and one pound is sufficient for one hundred welds.

Owing to the fact that the cost of welded joints is dependent upon and varies with the conditions surrounding each case, it would be difficult to make any estimate of the cost of the process for purposes of comparison with other systems of joining pipe lengths. It might be said, however, that the first cost of welding will undoubtedly be higher than any other system in use, but the *first cost* in the case of the thermit process is the only cost that will have to be met, since the joints, once welded, are permanent and as indestructible as the rest of the pipe. This cannot be said of any other system of pipe connections, and is a point that should be considered carefully by managers of steam, compressed air and refrigerating plants.

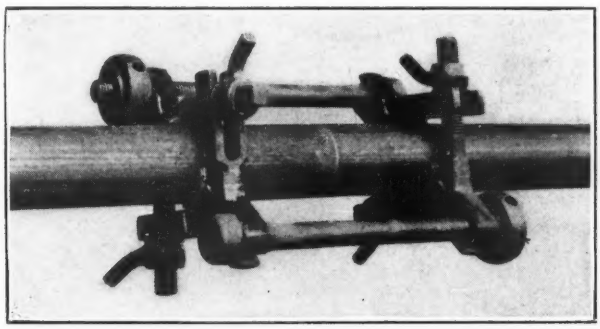
The Thermit process is controlled by the Goldschmidt Thermit Co., 43 Exchange Place, New York.

A NEW COURSE OF INSTRUCTION AT PRATT INSTITUTE

The department of science and technology of Pratt Institute, Brooklyn, N. Y., this year offers a new course in machine construction intended primarily to train its graduates to fill positions as foremen and assistant superintendents in machine shops or in kindred manufacturing plants in which machine work is an operation of first importance. It is preferred

that applicants for this course be men with some considerable previous experience in machine work, it being the idea to combine with their practical experience the theory underlying it. A good working knowledge of arithmetic is also required, and only those are desired whose ambition is to improve their condition and to that end are willing to devote their energies for the nine months required to complete the course. The machine shop of the institute has recently been added to, and the increased floor space and new equipment nearly double its capacity.

The course of study covers machine construction, tool working, lectures on machine shop practice, mechanical drawing, practical mathematics, foundry work and forging. A unique feature in the curriculum of the institute is the provision for developing in the students the ability to direct the work of others by giving each one practice at being a foreman, first over one or two of his classmates. and finally he is given a chance to lay out and direct the work of a larger number. In this way he is able to gain experience and confidence in handling men and in directing work, fortifying himself against the natural disinclination employers have for intrusting the responsibility of handling men to those who have never had actual experience.



CLAMP IN POSITION FOR WELDING PIPE BY THE THERMIT PROCESS.

WESTINGHOUSE COMPRESSOR FOR GARAGES

The Westinghouse Air Brake Company have put upon the market a portable air compressor particularly well adapted for automobile garages for inflating tires, dusting out vehicles and cleaning machinery of all kinds. The ease with which it can be moved about to any desired point makes it especially desirable for this purpose. These portable plants are extensively used in car barns throughout the country for cleaning cars and machinery. Their steam-driven compressors for industrial purposes are the same seen in daily operation on any locomotive for supplying compressed air to operate the train brakes, which attests their sturdiness and reliability.

During the past few years the knowledge of their efficiency and compactness has led to their rapid introduction into the industrial field, where they are employed for all conceivable purposes, as, for instance, raising water by direct pressure, operating pneumatic tools, paint sprayers, etc.; also for sewage ejecting systems, cleaning molds and machinery in foundries and shops and other uses too numerous to mention.

This is one of the most efficient labor saving devices lately offered to garage owners and ought to attain prompt popularity.

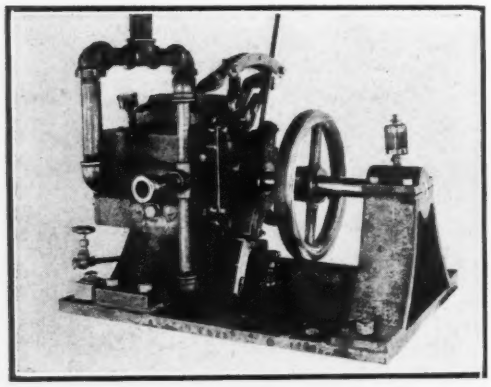
INDEPENDENT PNEUMATIC TOOL CO.

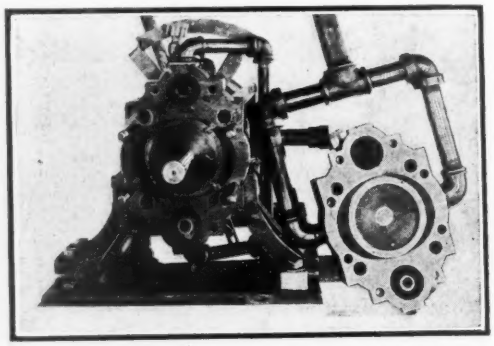
The Aurora Automatic Machinery Company of Aurora, a subsidiary of the Independent Pneumatic Tool Company, reports that owing to expanding business the company's plant will be greatly enlarged. The company has a capital of $500,000, but no new stock will be issued to finance the improvement. Stockholders at their annual meeting elected the following directors: John P. Hopkins, M. S. Rosenwald, Simon Florsheim, J. J. McCarthy, John D. Hurley, A. B. Holmes, all of Chicago; James B. Brady and W. O. Jacquette of New York

City, and C. E. Erikson of Aurora, Ill. The following officers of the company also were elected: President, John P. Hopkins; first vice-president, W. O. Jacquette; second vice-president, John D. Hurley; treasurer, C. E. Erikson; secretary, A. B. Holmes. The directors declared a regular quarterly dividend of 3 per cent.

A NEW ROTARY STEAM ENGINE

Revolution in the use of steam as a power agency is predicted for the rotary engine invented by H. I. Call, of Spokane. The idea embodied in the Cali engine is absolutely different from that of the ordinary reciprocating piston engine. There is no piston. Instead there is a steamchest, inside of which is a cylinder, which rotates by pressure of steam against slidable blades, power being made available by a shaft attached to the rotating cylinder.





TWO VIEWS OF NEW ROTARY ENGINE.

The cylinder is readily rotated by the pressure of steam against the projecting ends of the sliding blades in the crescent-shaped steam chambers. As the cylinder revolves it constantly slides the blades back and forth through the arc-shaped slots holding them into the cylinder. The sliding movement of the blades corresponds with the pressure of the oval inner wall of the steam chest upon the points of the blades. When one end of the blade is passing the narrowest distance between the cylinder and the steam chest wall the other end is passing through the widest distance in the crescent-shaped steam chamber. The ends of the blades are fitted so tightly against the wall of the steam chest that not an atom can come between them. To reverse the engine steam is admitted through opposite valves, the exhaust escaping through separate pipes.

Mr. Call has completed two of the new model engines. One of them is running in his shop in Spokane. It shows remarkable strength, operating several large lathes, drills, saws and other heavy machinery. The engine is 6x7x11 inches, and occupies a floor space 15x20 inches with its fittings, with 14 inches to the top of the steam pipe and weighs 217 pointed by the Spokane chamber of comarea for six horse power, but Mr. Call declares he has developed 10 horse power.

Mr. Call has formed the Crescent Rotary Engine Company and has secured patents on his invention in the United States and England, as well as other foreign countries and it is proposed to build a factory for its manufacture.

C. M. Fassett, J. M. Fitzpatrick and Samuel Glasgow, members of a special committee appointed by the Spokane chamber of commerce, have made a report to that body in which they say the engine is a great improvement over the reciprocal steam engine and that because of its cheapness, simplicity, compactness, easy control of speed and reversing and freedom of vibration the demand for it should be enormous. They also recommend the engine to the manufacturers of Spokane and endorse the project to manufacture it in Spokane.

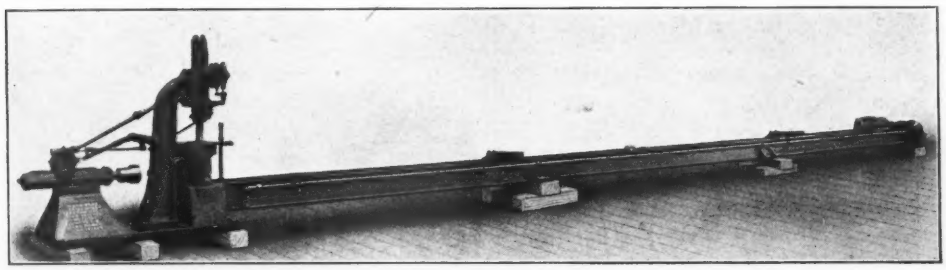
Messrs. Siemens and Halske, of Berlin, Germany, have recently patented an alloy which is

especially suited for use as a bearing metal. They state that it is superior to the usual white metal in that it is very easily worked and particularly easily turned, that it fills up the mold completely when cast, that it possesses relatively great hardness, and, what is most important, that it has an extremely small coefficient of friction. The alloy is made by melting together approximately equal parts of cadmium and zinc, with an addition of a small proportion of antimony. The alloy can, for example, consist of 45-50 parts of cadmium, 45-50 parts of zinc, and up to 10 parts of antimony. The antimony added should not exceed 10 per cent, as otherwise the metal is too brittle. A very suitable proportion of antimony is 5 per cent. If the proportion of cadmium and zinc is considerably varied, the coefficient of friction increases, and the other good properties of the alloy are essentially prejudiced.

"THE MULTEX"
(MULTIPLE EXPANSION)
COMPRESSED AIR-LIFT PUMP
(PRICE'S PATENT TAPER-TUBE SYSTEM.)

In a recent issue of our English contemporary *Engineering*, there appeared the following description of the test of a new air lift pump. Our contemporary states that although it cannot be claimed that the air-lift pump when used for raising water from deep wells and similar places, is able to compete in point of efficiency with high-class barrel pumps, it is, however, for many purposes so convenient and useful that there are many cases in which its advantages out-weigh those of mechanically-driven pumps. Unfortunately, in some instances where air-lift pumps have been tried, it has been found that their efficiency has been rather low; and there has, no doubt, on this score, been somewhat of a prejudice against them, which, though not unnatural, has probably frequently prevented their use in places and under conditions for which they were well adapted. Although their efficiency has been lower than that of the deep-well barrel-pump, it has been improved of late years, and particularly so by the adoption of the tapered delivery-pipe, which now bids fair to bring the air-lift pump into greater favor.

The principle of the pump is, of course, understood by engineers; although perhaps the latest improvements that have been made in it are not so well known. In its simplest form it consists of a pipe, which is placed in the water to be pumped, a part of the pipe being in the water and a part out. Inside or outside this pipe is another tube, down which compressed air is forced, the bottom of the air-tube being so arranged as to de-



WORD BROS.' DRILL MAKER AND SHARPENER.

A NEW DRILL SHARPENER.

A noteworthy machine for making and sharpening rock drills has lately been built in San Francisco and shipped to the Panama Canal. The conditions in the Canal Zone, with reference to rock drills, were such that the ordinary drill sharpener would not meet the requirements, mainly for the reason that the drills used there are of greater size and longer length than those generally used in mining.

The machine is of the Word Bros.' type of drillmaker and sharpener, and was designed and constructed with a view to handling long lengths and large size steel. It forges and sharpens drills from 1¼ in. diameter to 5 in. diameter, and from 1 ft. to 30 ft. long without any change of dies or appliances in the different sizes and lengths of drills. Its weight is 6000 lbs. and is 38 feet long overall, and was the first drill sharpening machine constructed in San Francisco after the great fire.

liver the air inside the water-tube, which is open to the well at the bottom. Before the air is admitted the level of the water is the same in both tubes, but when the air-pressure is applied, the water in the air-tube is forced down and mixes with the water in the water-tube. When the air has forced all the water out of the air-pipe, it flows out itself, mixes with the water in the water-pipe, making the column lighter, and causing the water to rise to a height which bears a relation to the immersion, and consequently to the pressure of the air supplied.

A Mr. Crockford appears to have applied the principle in America in 1846, for the purpose of pumping petroleum from several Pennsylvania wells. After that time the invention lay dormant for some considerable time—indeed, until revived by Dr. Pohlé about 1898. It was then applied by him for raising water on a large scale in America.

The rising main of the ordinary air-lift pump is of equal diameter throughout, and experiments have shown that layers of air rise in the main alternately with water; and as the layer of air rises in the main, the pressure above it, of course, grows less, at the top the pressure being only that of the atmosphere. If it can do so, the air will expand gradually on its way up, until at the top the length of tube that it occupies will be several times greater than that which it occupied at the bottom; or, in other words, much of the energy of the air is absorbed by giving the water a rapid motion, which is not required. This point has been very carefully studied by Mr. Joseph Price, of Messrs. Le Grand and Sutcliff, Bunhill-row, London, who has for a long time been investigating the matter, with the result that the firm mentioned have introduced a form of air-lift in which the rising main is gradually widened from the bottom towards the top. By this arrangement it will be seen that the air can expand laterally, and the layers of water will have only a slightly higher velocity at the top of the pipe than at the bottom. The energy expended in giving a higher momentum to the water as it rises is thus saved.

Very striking results have been obtained with this form of pump, much higher efficiencies being obtained by it than with the original apparatus, and several extensive experiments have been made in order to test the new arrangement. One of these, which we recently saw carried out at the Wandsworth and Putney Gas Works, is of so much interest that we place the results before our readers.

The air-lift pump on which the tests were made was placed in an artesian-well boring 7¼ in. in diameter, which extends to a depth of 630 ft. below the surface, and terminates in hard chalk. The well is lined continuously with steel tubes to a depth of 284 ft. below the surface, the upper part being surrounded by another steel tube 11½ in. in diameter, which reaches to 54 ft. below the surface; the space between the inner and the outer tubes being filled with cement-concrete, so as to protect the tube proper from any corrosive action of the waters of the surface beds. The "rest" water-level, before pumping, stood at about 154 ft. below the surface; and, during a preliminary test, indications of a probable supply of 5000 gallons per hour being obtained, arrangements were made for raising that quantity.

The pump employed was one of the "Multex" air-lift pumps on Price's patent taper-tube system, and the compression of the air was effected by a horizontal tandem steam-driven compressor of 12-in. stroke, with two-stage compression. All the cylinders were double-acting, the steam cylinder being fitted with a piston slide-valve, and the air-cylinders with Matthewson's inlet and delivery valves. The air, partly compressed in the first cylinder, was passed through an intercooler fitted with copper tubes; the cooled air then entering the high-pressure cylinder was further compressed to the working pressure, and delivered to a steel receiver, where any oil carried from the cylinders was deposited. From the receiver the air was conveyed a distance of 120 ft. to the air-lift pump, where it was connected by a length of metallic hose to the air-pipe passing down the well (in this case outside the rising main) to an annular ejector at the bottom. By a special arrangement the whole could be raised or lowered, and the annular passage through the delivery valve of the ejector increased or decreased, as desired, to ensure the most effective action.

The proper size of the annular opening once having been found, no further adjustment is required. The effective length of the rising ft., and a pressure gauge on the air receiver gave the pressure of the air and its equivalent head in feet. The immersion could thus be measured by simple inspection. The head, due

to the working pressure on the gauge, was 330 ft., 6 ft. of which was found to be due to friction in the pipes, leaving 324 ft. as head; and this, subtracted from 580 ft., the total length of the rising main, gives the effective lift as 256 ft., the delivery was some 33 ft. above the surface; so that the water level in the well while pumping, stands at 223 ft. below the surface, or 69 ft. below its normal level.

The water, after being delivered to an open cistern, to allow the air to separate from it before delivery into the distributing system of the gas works, was, for test purposes, passed through a valve into a tank provided with steadying screens, and a weir 1 ft. wide; the height of the still water was recorded on a strip of paper on a drum rotated by clockwork, thus furnishing a timed record of the actual flow over the weir.

During the test the air-compressor was run at 150 revolutions and at 160 revolutions per minute; the recorder showed an average flow of about 2 in. over the weir, or about 15 cubic feet per minute, and the efficiency of the compressor was then taken on the method usually adopted, of counting the number of strokes required to fill a measured receiver from atmospheric pressure to the working pressure, and correcting for differences of temperature, to ascertain the volume of free air actually compressed for this purpose. The measurement of the receiver was 9.6 cubic feet, or, with the pipes and valve chambers, exactly 10 cubic feet; which space was filled to 135 lbs., the working pressure, by 164 strokes (the average of three observations), which, with corrections for temperature, means a compression of 0.51 cubic feet of free air per revolution of the engine. Thus, at 150 revolutions, and 0.51 cubic foot per revolution, 76.5 cubic feet of air were compressed to raise 13¼ cubic feet of water, or a ratio of air to water of 5.8 to 1, and this while raising the water 256 ft., with an immersion of 324 ft., or a ratio of 56 per cent. of the total length of the rising main. Further particulars of the tests are given below:

Revolutions of compressor per minute	150	160
Free air compressed, in cubic feet	76.5	81.6
Height of flow over 12-in. weir	1⅞ in.	2 in. full
Equivalent delivery in cubic feet	13.2	14.54
Volume of air per volume of water	5.8	5.61
Horse-power equivalent of water lifted	6.4	7.04
Horse-power as per indicator diagrams from steam cylinder	17.8	19.6
Efficiency of plant	36 p. c.	36 p. c.
Ratio of immersion to height of rising main	56 p. c.	56 p. c.

As the quantity of air required increases materially as the proportion of immersion to lift decreases, to enable comparisons to be made, it is essential to reduce records to a common standard, preferably 60 per cent. of immersion to 40 per cent. of lift, which has been found to give the best results. The correction of the above figures to this standard gives the volumes of free air required per cubic foot of water raised as 5.05 and 4.87 cubic feet respectively; and as under similar conditions the best records of other air-lift pumps indicate a probable requirement of about 8 cubic feet of free air to be compressed, the claim that the tapering tube-pump will raise half as much more water as can be done with parallel tubes, with the same power, seems to be supported; the exact ratio in this case in 160 to 100.

Although the air-lift pump is not so efficient as a first-rate barrel pump, it is obvious that it has advantages under certain conditions, one of the greatest of these being that the working parts and machinery may be at a great distance from the well.

Another advantage is that it is quickly and easily installed. Now that the efficiency of this system has, by the use of the tapered pipe, been so much increased, there does not seem any reason why the air-lift pump should not be more used than it has hitherto been.

FLOOR SCRUBBING MADE EASY

Elias B. Dunn Exhibits Mechanical Invention Which Simplifies Laborious Process

If Elias B. Dunn has his way the day of the scrubwoman is over. So is the day of shaking out carpets and laborious washing of floors for the housewife. Mr. Dunn gave a demonstration of the inventions which have brought this about in the offices of the Dunn-Locke Vacuum Cleaning Company, in the Knickerbocker Building, No. 116 West Thirty-ninth street, yesterday.

The device is like the ordinary vacuum cleaning apparatus, except that its rubs the floor,

sucks up the soap and water and carries all the refuse back through a rubber tube and thence to the cellar with a pump, which discharges the stuff.

Mr. Dunn threw flour and other things over the upholstery of his office furniture, and showed how the appartus cleaned it all off in a few seconds and left not a stain behind.

THE Traylor Engineering Co., which has recently begun the manufacture of fuel briquetting machinery, and the installation of fuel briquetting plants under the Mashek system of briquetting, has already received several important orders. Three of their orders, for which the machinery is now being built at the company's works, at Allentown, Pa., are, respectively, for Edward B. Arnold, No. 1 Broadway, New York, for his plant at the foot of West 48th street, New York; the Semet-Solvay Co., for its Detroit plant, and the Montreal Light, Heat and Power Co., of Montreal, Canada.

These plants represent three interesting variations of the briquetting industry. Mr. Arnold is a large coal dealer. His plant is to make briquettes for domestic consumption, using the small sizes of anthracite coal. The Semet-Solvay Co. will make first-class fuel for domestic use from the coke breeze, which is a waste product from the Solvay by-product coking ovens, and the Montreal Light, Heat and Power Co. will make a smokeless briquette for family use from coke breeze resulting from gas making, using coal tar pitch as a binder.

The adoption of the Mashek process and machinery by these three concerns is of particular significance because each of them has been experimenting for a long time with the best and most used European briquetting machinery, and machinery of other design until they were all of them conversant with every system in use. Although the foreign process and machinery may be satisfactory abroad, they have proved a commercial failure here. The briquettes produced are not of a size or shape to suit American consumers, most of them requiring to be broken up before use. Their cost also was too great, because of the small production of the plants, the large amount of binder required, and the cost of the necessary attendance. The Mashek plants and machinery are entirely automatic in their operation, no hand-labor being required from the time the materials are received until the finished briquettes are ready to be delivered to the consumers. The briquettes are of a size and shape suitable for immediate use and convenient to handle by chute or shovel, and the production is nearly as large per hour as is the daily output of tthe foreign built plants. The briquettes are as hard and clean as anthracite coal and equal the best qualities of anthracite for use. The cost of briquetting under this system has been demonstrated in plants now in operation to be from 76c. to 92c. per ton, including pitch for binder, fuel for the boilers, dryers and heaters, lubricating oil, wear and tear and labor—in fact, including everything but the cost of the raw material to be briquetted. The system operates equally well on anthracite or bituminous coal, coke breeze or lignite. The design of the machinery and the installation of plants is under the personal supervision of Mr. G. J. Mashek, the inventor and patentee of this process and machinery.

TRIAL OF ROCK DRILLS, AT BENDIGO.

Trials were made at Bendigo, on December 21, 1905, at the 1,470 ft. level of the Suffolk Tribute mine, with various water sprays and atomizers. Before drills started, 24,000 dust particles to the cubic centimetre were found, and in two and a half hours had increased to 270,000. The approximate average weight would be about 70 billions to the gramme. Conclusions drawn from the various experiments made are:—(1) Large particles are only found during boring in dry holes, and are quickly settled by gravitation. They are probably too short in the air to be inhaled in dangerous quantities, and water drills or atomizers easily eliminate even the possibility. (2) Medium sized particles are thrown into the air in large numbers by dry drills, and render their imemdiate locality very dangerous to health. Their production in the air may be checked by water drllls, and the atomizer soon causes them to settle if properly directed. (3) Small particles are always found in mine air in varying quantity, and possibly include a larger portion of living organisms than in the open air. Prolonged use of water drills or atomizers tends to reduce their numbers, but produces possibly injurious humidity instead.—*The New Zealand Mines Record.*

CHIPPINGS.

MRS. Frances A. W. McIntosh, formerly advertising manager of the Standard Tool Co., Cleveland, O., and more recently connected with the advertising department of Power, New York, has taken charge of the Publication Department of the Norton Company, Worcester, Mass.

The compressed air systems are being extended at the navy yards and further improvements in the methods of transmission are under consideration. The use of tools operated by compressed air is increasing and plans have been made to make the facilities more accessible.

The deepest bore hole in the world is one that is located near Leipsig, Germany. The object of the hole was in determining whether coal was there and likewise the man making the boring was of a scientific turn of mind. The hole has attained the great depth of 5,790 ft. At the surface the hole was about a half foot in diameter and at the bottom had tapered off to less than an inch in diameter. Diamond drills were used and the rods weighed 20 tons. It took ten hours' work to take the rods apart and put them together again.

Compressed air differs from electricity, especially in the fact that electrical friction losses cannot be regained, while corresponding losses with compressed air may be eliminated. The moderate fall in pressure in the air due to friction augments the volume of the air and does not involve a loss of transmission. "If the air were at 80 lb. gage or 95 lb. absolute upon entering the pipe, and 70 lb. gage or 85 lb. absolute at the other end, there would be a loss of a little more than 10 per cent. in absolute pressure, but at the same time there would be an increase of volume of 11 per cent. to compensate for this loss of pressure, and the loss of available power would be less than 3 per cent."

Where compressed air is used, it is important that all joints in the air mains should be carefully made to prevent any possible leaks, as air leaks are more expensive than steam leaks. At intervals, it is well to test for leaks by allowing the air at full pressure to remain in the pipe long enough to observe the gage. To render pipes accessible for inspection, they should, if buried, be carried in boxes sunk just below the surface of the ground, and all low points which might form pockets for the accumulation of entrained water should be avoided, as they obstruct the passage of the air. It is also advisable, in long, uneven lines, to provide an opening near the end, for occasionally blowing out water. Long lengths of pipes on the surface or shafts where the temperature is subject to changes, should be provided with expansion joints.

The pneumatic tube as a feature of the mail service seems finally coming into its own, after years of interesting and peculiar struggle, such as no worthy labor-saving device probably ever has to go through until it strikes the tortuous ways that lead to Government adoption. But in spite of all, the pneumatic tube which has long been an established time and money saver in private establishments, which has hustled express from city to suburb, is to be much more in evidence in Uncle Sam's mail service. Bids have been opened recently for renewal of contract and extension of the service in New York, Brooklyn, Philadelphia, Chicago and St. Louis; for renewal of contract in Boston, and for new service in Pittsburgh, Baltimore, Cincinnati, Kansas City and San Francisco. Appropriations not to exceed $1,250,000 a year for the service are now available, and extend over a period of ten years. These should give the Postmaster-General a rather free and generous hand in getting from the pneumatic tube a service most valuable and time-saving in many parts of the country.

To produce a black color on brass, the following is the formula: Dissolve 1 pound of plastic carbonate of copper in 2 gallons of strong ammonia; first boil the brass that is to be blackened in a strong potash solution to remove all grease and oil; rinse well and dip in the copper in the ammonia solution, which should be heated to 150 to 175 deg. F., until the desired degree of blackness is acquired. The color produced is very uniform and has little tendency to peel off. The process works best on brass containing much copper, or on what is known as "red" brass. Directions are also given for making the plastic carbonate of copper as follows: Blue vitriol (sulphate of copper) is dissolved in hot water and a strong solution of common washing soda is added to

it so long as any precipitate forms. The precipitate is allowed to settle and the clear liquid is poured off. Hot water is now added, and the mass stirred and again allowed to settle. Again the clear water is poured off and the operation of adding hot water settling and pouring off is repeated until everything has been washed out of the green carbonate of copper which remains at the bottom of the vessel. This is the plastic carbonate of copper referred to.

WELLS AND THE WEATHER

According to the observation of M. Grosseteste upon some of the wells which are situated in the Canton of Geneva, it appears that the wells have the remarkable property of drawing in air at certain times and of blowing out air at other periods. These wells are considered by the inhabitants of these districts as very exact indications of the weather. When the wells blow out air it is a sign that rain is to follow, and when air is drawn in it is a sure indication of fine weather. Since the wells are covered with a flat stone having a hole in it, according to the custom of the region, it is easy to observe the direction which is taken by the current of air. Some observers installed upon one of the wells a pressure gauge of U-form, and were thus able to find some interesting points about the air currents. Thus they find that a well is very seldom in a state of equilibrium. It blows out when the barometer falls and sucks in air when it rises. These variations do not exceed a height of one inch on the gauge. As to the theory of the action of these wells, it is to be remarked that they lie in strata of alluvial gravel covered with vegetable earth which is quite or nearly impervious to water. We may therefore admit that, owing to the spaces which exist between the stones of the gravel, these strata form a reservoir of great capacity in which the water circulates. The water comes into the cavities when the atmospheric pressure is lowered, and it leaves them when the pressure rises. The effect of these movements is thus felt within the well, inasmuch as the latter forms the connecting point with the outer air. This phenomenon may be said to have a considerable analogy with the emission of gases by certain hot springs, to caves where a current of air circulates upon the ground, to the variations in the flow of springs and other phenomena of a like nature.—*Scientific American.*

It was recently noticed in a cold storage that candles or lamps began to burn with a feeble flame as soon as they were brought into the room and that in many parts of it they were extinguished. A match could be lit, but the wax would not ignite. In the corner of the storeroom was a disused well, from which gas issued, and Mr. Bertram Blount, who was asked to investigate the cause of the trouble, at first supposed that carbon dioxide was being distributed into the air from this well. But this was not borne out by analysis of the air in the room and from the well, says Knowledge and Science, for the amount of carbon dioxide was only slightly more than is present in normal air, and was quite insufficient to have affected the combustion of a candle. Samples of the air taken from different parts of the room contained only 17.5 to 17.7 per cent. of oxygen, or from 3.2 to 3.4 per cent. less than is present in normal air. The oxygen in the air in the shaft of the well amounted to no more than 8.6 to 8.9 per cent., and other experiments confirmed the conclusion that the air in the storeroom was ordinary air containing less than its proper proportion of oxygen, owing to admixture of air deprived of its oxygen, which issued from the well shaft. The source of the impoverished air from the well was finally traced to tunneling operations close by, in which compressed air was being used. The air must have found its way through the soil wherever it was sufficiently porous, and so into the shaft of the well, and on its passage through the soil must have been deprived of part of its oxygen by contact with some substance such as pyrites. Evidence in support of the correctness of this conclusion was furnished by the analysis of the mud from another well shaft near the first. This mud was found to contain pyrites, and air left in contact with it for some weeks was deprived of almost the whole of its oxygen.

ONE of the causes of a serious loss in the transmission of compressed air is pumping the air of the engine room rather than air drawn from a cooler place. This loss amounts to from 2 to 10 per cent.

U. S. PATENTS

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Full specifications regarding any of these patents may be obtained by sending five cents to the Commissioner of Patents, Washington, D. C. (Stamps will not be accepted.)

830,618. FAN FOR PNEUMATIC STACKERS. JOSEPH K. SHARPE, JR., Indianapolis, Ind., assignor to the Indiana Manufacturing Company, Indianapolis, Ind., a Corporation of West Virginia. Filed Apr. 17, 1905. Serial No. 256,106.

Claim.—1. The combination, with a fan-vasing having an eye leading thereinto, of a fan rotatably mounted within the casing, and a guard consisting of a series of substantially concentric separated portions arranged between the eye of the casing and the fan.

830,661. PNEUMATIC KNEE-PAD. ERNEST G. GRESHAM, Dunedin, New Zealand. Filed Jan. 6, 1906. Serial No. 294,970.

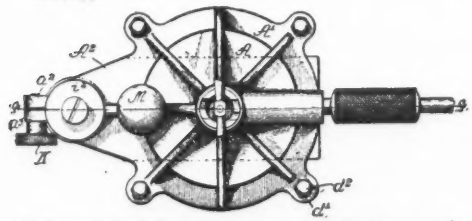
830,975. APPARATUS FOR PRODUCING HIGHLY-OZONIZED AIR OR OXYGEN. AUGUSTE

831,040. LOAD-BRAKE APPARATUS. JOHN S. CUSTER, Pittsburg, Pa., assignor to The Westinghouse Air Brake Company, Pittsburg, Pa., a Corporation of Pennsylvania. Filed Dec. 18, 1903. Serial No. 185,679.

831,044. EXPLOSIVE-ENGINE. HERMAN DOCK, Philadelphia, Pa. Filed Nov. 6, 1903. Serial No. 180,005.

Claim.—In an explosive-engine, in combination, a cylinder, a carbureter, connection between the carbureter and the cylinder, a source of air-pressure supply, a pipe leading therefrom to the carbureter, a pipe leading from the atmosphere to the carbureter, and means to connect the carbureter with either the atmosphere or the air-pressure supply.

831,272. PNEUMATIC TOOL. NATHAN W. FLETCHER, Chicago Heights, Ill., assignor to Turbine Motor Tool Company, Chicago, Ill., a Corporation of Illinois. Filed May 16, 1904. Serial No. 208,244.



Claim.—A tool for the purposes set forth, comprising a main frame embracing a base having a flat, bottom bearing-surface, a turbine-motor, the rotative member of which is mounted centrally over the base with its axis of rotation vertical and the non-rotative member of which is rigidly attached to said base and constitutes a part of the frame, an upright tool-shaft located outside of said base, a rigid arm on the frame affording a bearing for said shaft, end bearings for the shaft which are adjustable on said arm in a direction endwise of the shaft, and gearing connecting the rotative member of the motor with said tool-shaft.

831,275. APPARATUS FOR HUMIDIFYING AND CLEANSING AIR. JOHN W. FRIES, Winston Salem, N. C. Filed April 24, 1902. Serial No. 104,481.

831,284. PROTECTIVE DEVICE FOR VENTILATING-FANS. ROBERT A. ILG, Chicago, Ill., assignor of one-half to Theresa Ilg, Chicago, Ill. Filed Feb. 3, 1905. Serial No. 244,028.

831,373. AIR-BRAKE ATTACHMENT. JAMES B. O'DONNELL, Freeland. Pa. Ffled Nov. 20, 1905. Serial No. 288,190.

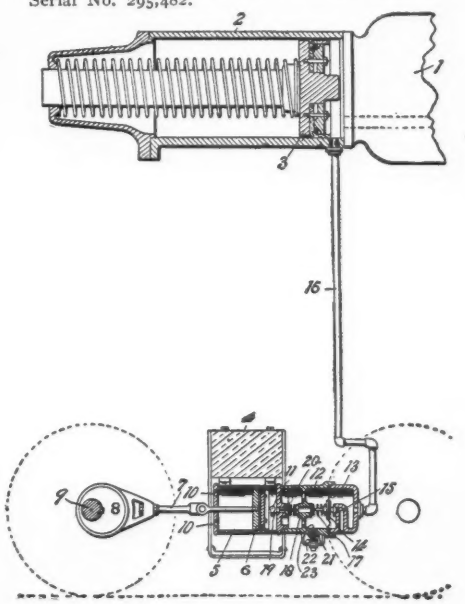
831,418. AUTOMATIC AIR-BRAKE SYSTEM. FRED B. COREY, Schenectady, N. Y., assignor to General Electric Company, a Corporation of New York. Filed Dec. 19, 1903,. Serial No. 185,794.

831,540. ELASTIC-FLUID TURBINE. CHARLES G. CURTIS, New York, N. Y., assignor, by mense assignments, to General Electric Company, a Corporation of New York. Filed Dec. 11, 1903. Serial No. 184,746.

831,677. PRESSURE-REGULATOR. ANTHONY L. NOONE, New York, N. Y. Filed March 22, 1905. Serial No. 251,408.

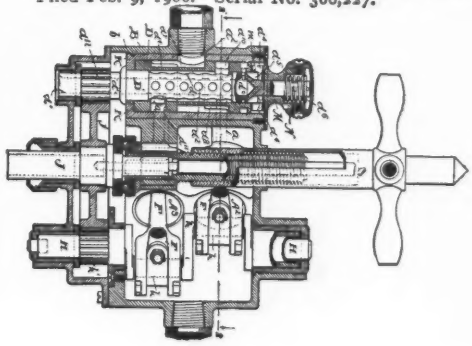
831,739. PRESSURE-REGULATOR. ANTHONY L. NOONE, New York, N. Y. Filed March 22, 1905. Serial No. 251,409.

831,795. HIGH-SPEED BRAKE. WILLIAM B. MANN, Baltimore, Md., assignor to American Air-Brake Company, a Corporation of New Jersey. Filed March 5, 1903. Renewed Jan. 10, 1906. Serial No. 295,482.



Claim.—In a high-speed brake, the combination of a brake-cylinder, with a relief-valve, a movable member secured thereto, devices exerting a constant force

831,824. VALVE FOR FLUID-PRESSURE MOTORS. SIDNEY W. BRAINARD, Cleveland, Ohio, assignor to The Cleveland Pneumatic Tool Company, Cleveland, Ohio, a Corporation of Ohio. Filed Feb. 9, 1906. Serial No. 300,227.



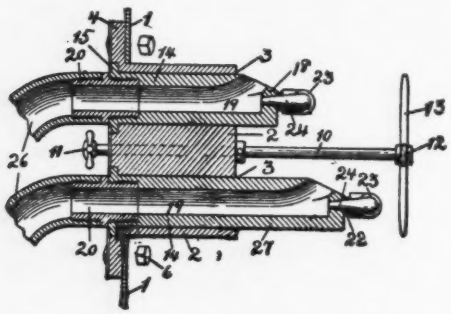
Claim.—In a fluid-pressure motor, the combination of a cylinder, its piston, a crank-shaft, and connections between said crank-shaft and piston, with a rotary valve consisting of two concentric parts, to wit, a tubular shell having an exhaust-port through its wall, and an inlet-port in its surface, and a stem having a longitudinal hole open at one end, and one or more transverse holes through its wall connecting with said longitudinal hole, there being an annular space between the valve-shell and stem, mechanism adjustably connecting said shell and stem, and mechanism transmitting motion from the crank-shaft to said stem.

831,864. RETAINING AND RECHARGING VALVE FOR AIR-BRAKES. CLAUDE B. HARRINGTON, McMechen, W. Va., assignor of one-half to Harry A. Uhler, W. J. Duffy and O. L. Simms, McMechen, W. Va. Filed Sept. 25, 1905. Serial No. 280,096.

831,930. MOTOR OR ENGINE. CHARLES C. CLARK, Corning, N. Y. Filed Sept. 13, 1905. Serial No. 278,327.

Claim.—An engine or motor provided with pneumatic driving means, electrical driving means, and a generator adapted to be operated by air-pressure from the pneumatic driving means and to supply current to said electrical driving means.

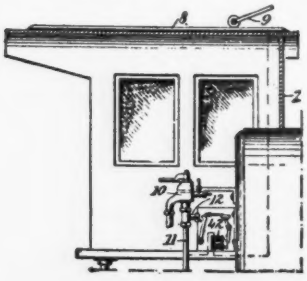
831,970. PNEUMATIC SANDER. JOHN J. MORGAN, Baltimore, Md., assignor to John C. Hooper and Thomas M. Hanson, Baltimore, Md. Filed June 19, 1906. Serial No. 322,398.



Claim.—A pneumatic sander comprising a sand-receptacle; a plurality of sand-distributing devices sustained in said receptacle in different horizontal planes and air-tubes in the receptacle and also arranged in different horizontal planes.

832,038. PNEUMATIC VALVE. HAMPUS A. CARLSON, Bridgeport, Conn. Filed April 26, 1906. Serial No. 313,897.

832,306. PNEUMATIC BRAKE-VALVE. GEORGE P. FINNIGAN, Greene, N. Y. Filed Aug. 26, 1904. Serial No. 222,240.

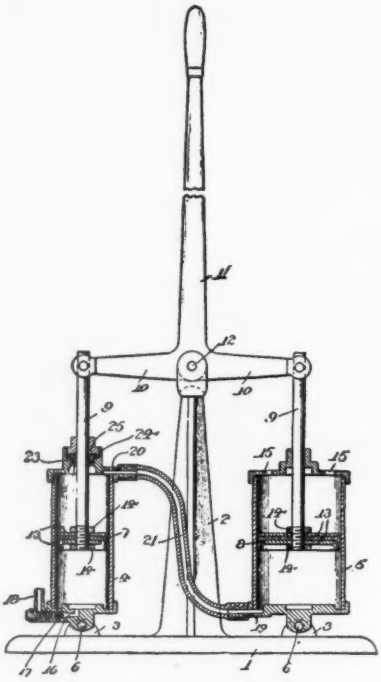


Claim.—In a pneumatic brake-valve, the combination of a hollow pneumatic member provided with an opening, a disk of glass disposed adjacent to said opening and having a convex conformity for the purpose of resisting air-pressure, and means for automatically breaking said disk so as to allow the free passage of air through said opening.

832,374. MOUTHPIECE FOR PNEUMATIC TEAT-CUPS. ALEXANDER GILLIES, Geelong, Victoria, Australia. Filed March 22, 1906. Serial No. 307,454.

832,375. PNEUMATIC HEEL-CUSHION. WILLIAM L. GORDON, Deal, N. J. Filed Dec. 13, 1905. Serial No. 291,562.

382,567. COMPOUND AIR-PUMP. HOWARD WIXON, Chicago, Ill., assignor to Imperial Brass Manufacturing Company, Chicago, Ill. Filed April 13, 1905. Serial No. 255,291.



Claim.—A compound pump comprising high and low pressure cylinders having inlets at adjacent ends and outlets at the opposite adjacent ends and having an unobstructed passage leading from the outlet end of the low-pressure cylinder to the inlet end of the high-pressure cylinder, and one-way yielding, cupped pistons in said cylinders connected to shift simultaneously in opposite directions, substantially as described.

832,673. PEDAL ATTACHMENT FOR PNEUMATICALLY-OPERATED INSTRUMENTS. NELSON D. HOSLEY, Meriden, Conn., assignor to The Wilcox & White Co., Meriden, Conn., a Corporation. Filed Sept. 14, 1905. Serial No. 278,410.

832,768. ELECTRIFIER FOR TREATING AIR OR OTHER GAS. JAMES H. BRIDGE, Philadelphia, Pa. Filed May 25, 1906. Serial No. 318,643.

832,780. FLUID-PRESSURE-ACTUATED MECHANISM FOR CONTROLLING GATES, VALVES, &c. GEORGE A. CUTTER, Nashua, N. H., assignor to Improved Paper Machinery Company, Castine, Me., and Nashua, N. H., a Corporation of Maine. Filed Feb. 14, 1903. Serial No. 143,339.

832,783. COMPRESSION OF ELASTIC FLUIDS. SEBASTIAN Z. DE FERRANTI, London, England. Filed Oct. 19, 1903. Serial No. 177,703.

Claim.—An elastic-fluid compressor employing a liquid as the medium of compression, comprising means for giving the liquid velocity, a plurality of fixed tubes or ducts receiving the liquid from such means through which the elastic fluid is compressed successively under pressure by said liquid and a means which said tubes connect for receiving the discharge therefrom.

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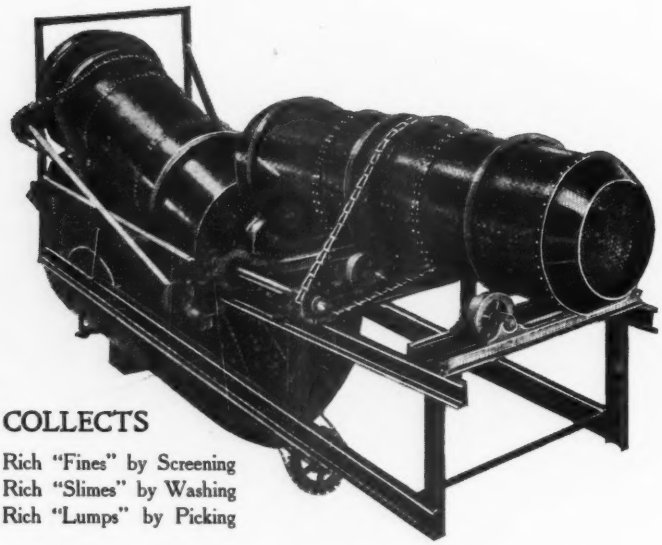

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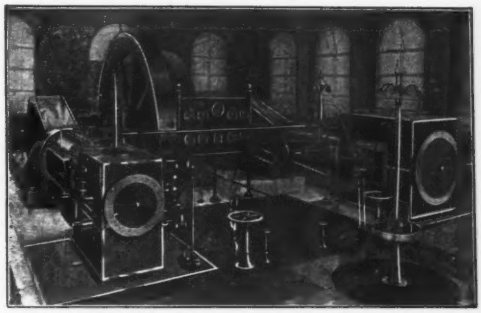

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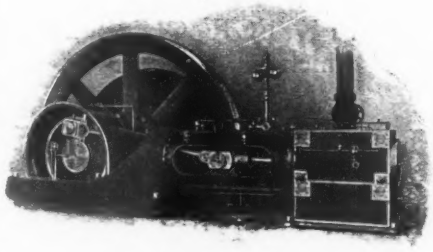

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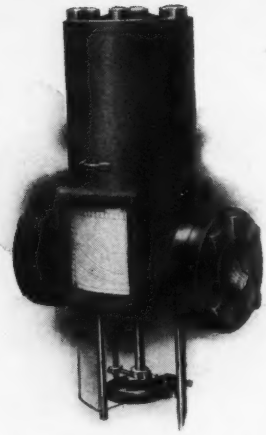

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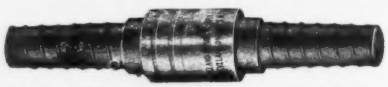

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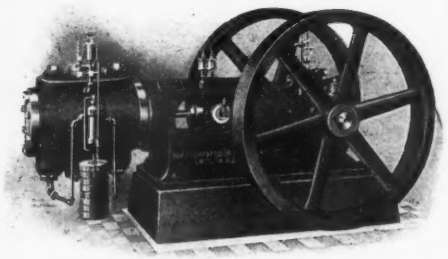

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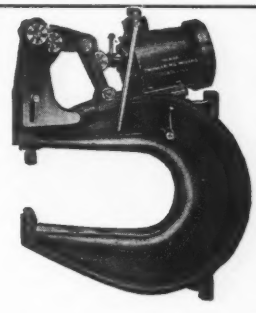

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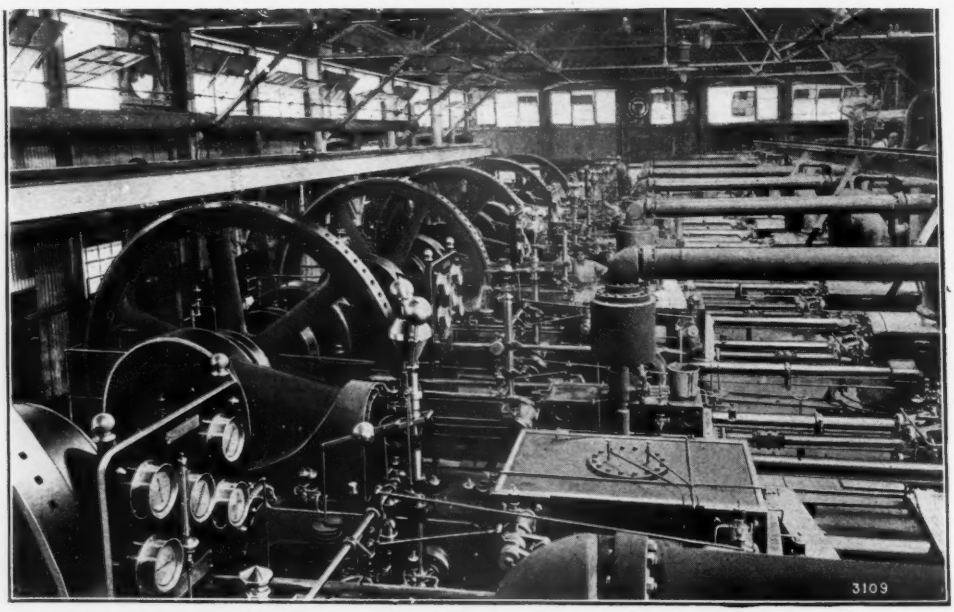

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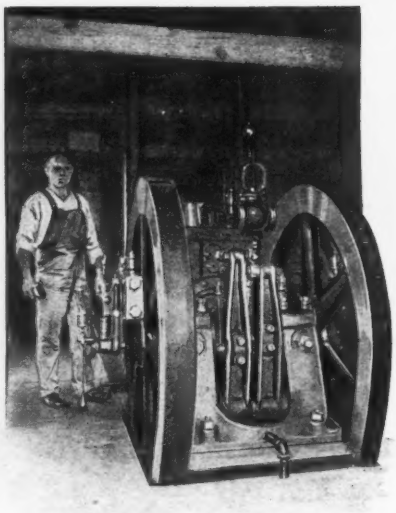

Sullivan Air Compressors.

This is one of three class W B-2 Sullivan Straight Line, Two-Stage Compressors used by Lane Bros. Co. on their tunnel contract at Lynch's Va. (Tidewater Railway).

Mine and Quarry

for November contains an account of construction progress on this railroad. Other articles: "Quarrying Marble in Georgia," "Cost of Drilling at the Wabana (Newfoundland) Iron Mines," "Machine vs. Hand Coal Mining."

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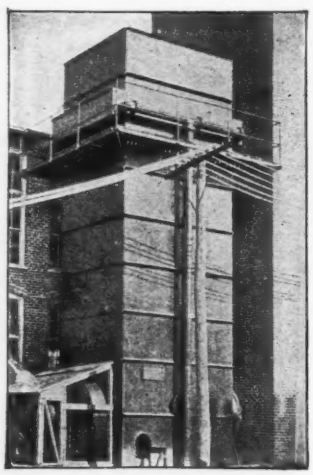

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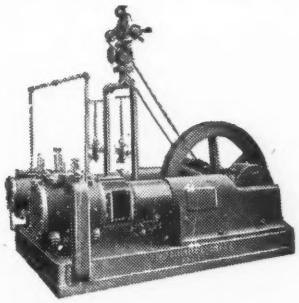

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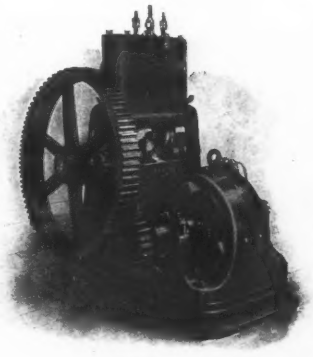

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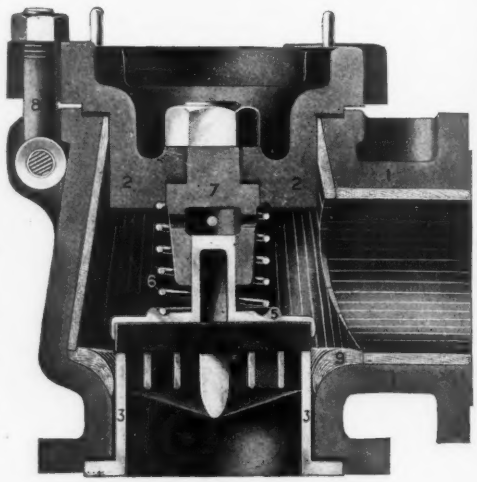

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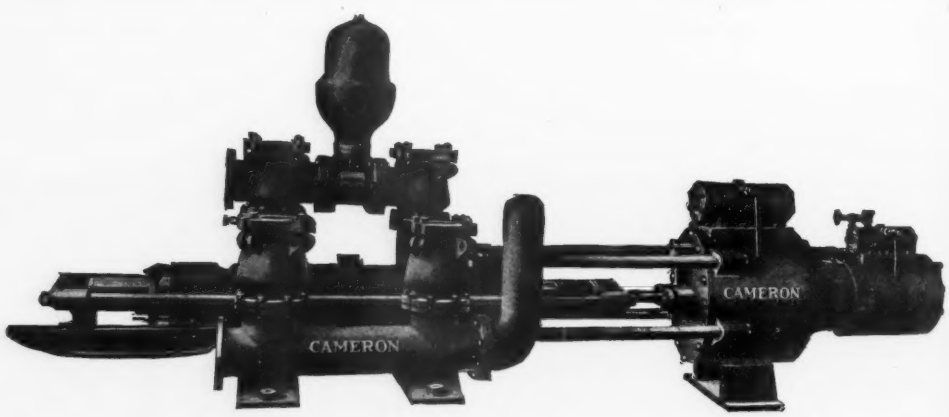

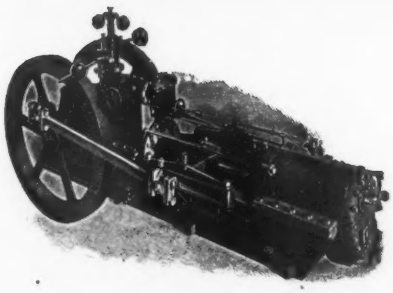

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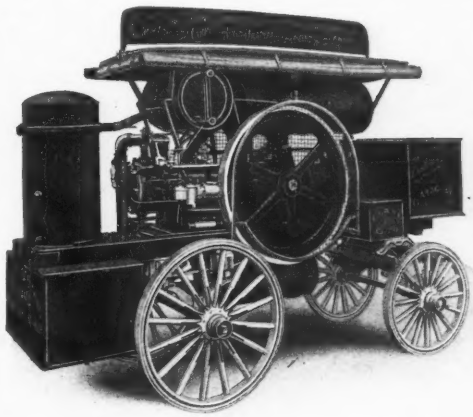

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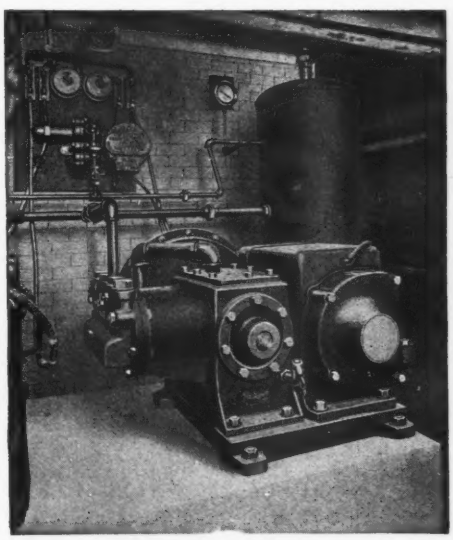

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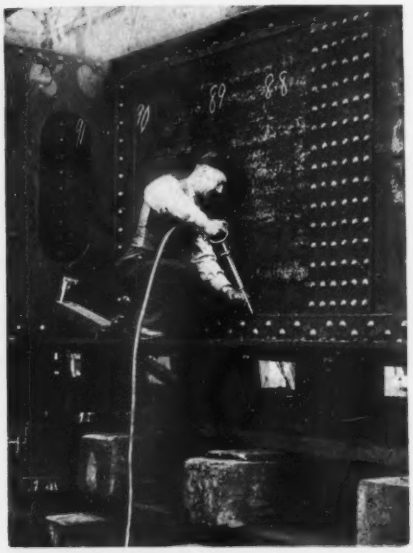

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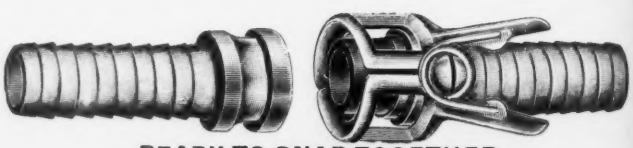

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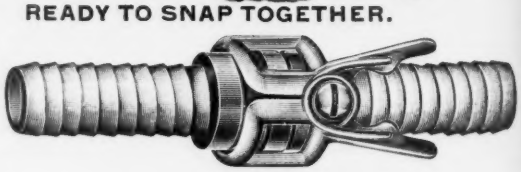

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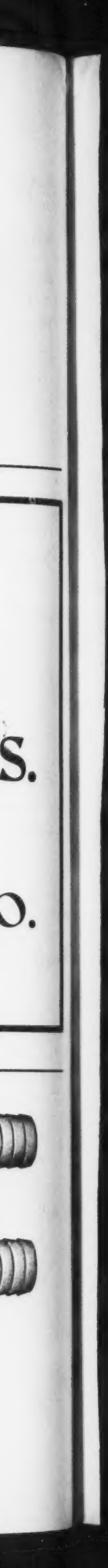
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